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PILOT-PLANT STUDY OF AN AMMONIA ABSORPTION-AMMONIUM BISULFATE REGENERATION PROCESS, TOPICAL REPORT PHASES I AND II

Tennessee Valley Authority

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The report gives results of the initial two phases of pilot-plant work done by TVA for the EPA on an ammonia absorption/ammonium bisulfate regeneration process for removing SO2 from stack gas of coal-fired power plants. The work was carried out sequentially in two pilot plants at TVA's Colbert Power Plant in northwest Alabama: the first plant was used to study the absorption process only; the second, to study both the ammonium bisulfate regeneration step and the absorption step. Both pilot plants were designed for about 4000 acfm of flue gas at 300F. The principal variables studied were: inlet flue gas temperature, recirculated absorber liquor pH, opacity of the plume leaving the absorber stack, oxidation of sulfite to sulfate in the absorber liquor, and the fly ash level in the flue gas entering the absorber.

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June 1974

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ABSTRACT

This report covers the pilot-plant work done through June 1973 by the Tennessee Valley Authority (TVA) for the Environmental Protection Agency (EPA) on an ammonia absorption - ammonium bisulfate regeneration process for removing sulfur dioxide (SO_2) from the stack gas of coal-fired power plants. This work was carried out sequentially in two pilot plants at the TVA Colbert Power Plant in northwest Alabama. The first pilot plant was used to study the absorption process only. This work was reported as Phase I. The second pilot plant was used to study the ammonium bisulfate regeneration step as well as the absorption step. This work was reported as Phase II.

Both pilot plants were designed for about 4000 acfm of flue gas at 300°F. Two types of scrubbers were studied—a sieve-tray type and a moving marble-bed type.

The principal variables studied were: temperature of the inlet flue gas, pH of the recirculated absorber liquor, opacity of the plume leaving the absorber stack, oxidation of sulfite to sulfate in the absorber liquor, and the level of fly ash in the flue gas entering the absorber.

This report was submitted in partial fulfillment of contract No. TV-31990A, by the Division of Chemical Development, Tennessee Valley Authority. The work was sponsored by the Environmental Protection Agency. Although the project is being continued, that part of the work reported here was finished in June 1973.

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CONCLUSIONS AND RECOMMENDATIONS

The two pilot-plant studies have demonstrated that the ammonia absorption - ammonium bisulfate regeneration process is a promising candidate for SO_2 removal and recovery from power plant stack gases. Conclusions drawn from the work are:

- Absorption is effective (90% or higher) over a wide range of operating conditions. The absorption efficiency can be reliably predicted for given operating parameters (see text).
- Sulfate levels in the absorber loop have only slight influence on SO_2 absorption.
- Fly ash has a neglible effect on SO_2 removal.
- Temperature of the inlet flue gas had very little effect on SO_2 removal in the range covered by the study (180°-300°F).
- Corrosion is not a problem in the absorption loop when using stainless steels and certain nonmetals. Corrosion tests in the regeneration loop have not been made.
- Plume formation while producing liquor with high-salt concentrations ($C_A > 12$) can be controlled by proper operation of the scrubber.
- Avoidance of a steam plume outside the stack on days of high relative humidity and low temperature may be impractical.
- Adequate separation of fly ash and ammonium sulfate crystals has not been achieved in the pilot-plant equipment; with proper equipment and operation, adequate separation is expected.

The evaluation and conclusions based on the past work indicate that additional work on the process is warranted. Additional study is needed to evaluate the entire process, absorption and regeneration, while operating on a continuous basis under conditions expected during power plant operations. This will require that the pilot plant produce and regenerate a solution containing high salt concentrations during cycling loads. The solids removal problems (fly ash and ammonium sulfate crystals) and corrosion throughout the process require additional work. To make these studies, certain equipment additions are needed. These include a separate water wash ahead of the present absorber and an ammonium sulfate evaporator-crystallizer in the regeneration section. Additionally, the ammonium sulfate decomposition step should be piloted.

SUMMARY

In 1968, the Environmental Protection Agency (EPA) commissioned the Tennessee Valley Authority (TVA) to pilot an ammonia absorption process for removal of sulfur dioxide from coal-fired power plant stack gases. Test programs were conducted sequentially in two pilot plants at TVA's Colbert Power Plant in northwest Alabama. The operation of pilot plant No. 1 (study of absorption step only) extended from June 1970 to December 1971. Operation of pilot plant No. 2 (absorption step coupled with a regeneration step) began in June 1972, and is scheduled to continue until July 1975. This report covers the test work through June 1973.

Both pilot plants were designed for about 4000 acfm[1] of flue gas at 300°F. Process equipment and materials of construction were selected to approximate a commercial process.

Two types of absorbers were tested—a sieve-tray unit and a moving marble-bed unit. Most of the test work was done with the marble-bed absorber.

The SO_2 removal efficiency was 90% or higher. The sulfate content of the feed solution had little (5% or less) effect on SO_2 removal efficiency.

The temperature of inlet flue gas had no significant effect on SO_2 removal efficiency in the range of 180° to 300°F. The heat capacity of the inlet gas was 0.26 Btu/lb(°F). The overall heat transfer coefficient of a mild steel tube- and shell-type heat exchanger in the inlet gas stream was about 2.9 Btu/hr(ft^2)(°F).

Data were obtained that showed the relationship of ammonia loss in the gases exiting the absorber as a function of the pH of the liquor recirculated to the top stage. Results indicate that the pH of the liquor must not exceed 6.1 in order to stay below the arbitrarily selected limit of 50 ppm ammonia in the exit gases.

A severe problem encountered during the study of both pilot plants was the emission of a highly visible plume of ammonia salts from the absorber. The plume was so severe that most of the program was directed toward defining operating conditions that would eliminate or reduce the plume to acceptable limits. A plume of acceptable opacity resulted when the absorber was operated with:

- Low ammonia concentration in the absorbing liquor and reheat as required to dissipate the steam plume (max. 200°F).

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[1] A table of factors for converting measurements made in English units to their equivalents in the metric system is shown in Appendix H.

- High ammonia concentration in the absorbing liquor, a water wash ahead of the absorber, the absorber and all downstream ducts insulated, and reheat as required to dissipate the steam plume. The quantity of reheat required for avoidance of a steam plume depends on the ambient conditions (temperature and humidity).

The variables affecting oxidation of sulfite to sulfate could not be accurately determined. From 10 to 30% of the SO_2 in the gas to the absorber was oxidized. Most of the results were in the lower end of this range—15% oxidation ordinarily.

The level of fly ash in the flue gas entering the absorber had no apparent effect on SO_2 absorption; however, the fly ash could not be removed satisfactorily from the absorbing liquor and adversely affected separation of sulfate crystals in the regeneration section.

The regeneration loop was designed to use molten ammonium bisulfate to acidify the absorber product liquor; however, sulfuric acid was used as a substitute. Approximately 97% of the absorbed sulfur dioxide was released during regeneration. The ammonium sulfate crystallized from the acidulated and stripped liquor could not be separated because of blinding of the (centrifuge or filter) media. Solids separation should be an area of major emphasis in the future work.

Corrosion tests were made in the absorber loop only. Mild steel was unacceptable at all absorber loop locations except the dry inlet ductwork. Type 316L stainless steel was acceptable in all environments in the absorber loop. In areas where temperature limitations were not exceeded, certain nonmetallic materials of construction appeared promising. Corrosion tests are planned for the regeneration loop.

The pilot-plant study demonstrated that the ammonia absorption process is capable of decreasing the SO_2 content of gases from a coal-fired boiler to well within an acceptable level in commercially available equipment. Results of these studies provide a background of data and experience for additional pilot-plant operation involving detailed studies of the ammonium bisulfate regeneration system.

INTRODUCTION

In 1968, the EPA contracted with TVA to make an in-depth study of the ammonia absorption process. The purpose of the study is to gain engineering information about the ammonia system when applied to actual power plant stack gas. The ammonia process was selected for study because ammonia is widely available, relatively low in cost, easy to handle, and has a high affinity for SO_2. In addition, the reaction products are soluble salts which avoid the scaling and plugging problem of some alternative processes. Furthermore, the ammonia reaction products are amenable to regeneration to recover the SO_2, which is further processed to sulfuric acid or elemental sulfur. In such systems, ammonia is recovered and recycled to the absorption section to complete the regeneration cycle.

Sulfur dioxide removal from gas streams using ammonia absorption was studied as far back as 1883 when a British patent was issued to Ramsey (1). In these early studies, ammonium sulfate was the desired product. Around 1936 the Consolidated Mining and Smelting Company (2) (now Cominco, Ltd.), installed a commercial ammonia absorption unit for removal of sulfur oxides from waste smelter gases. Products from the unit were ammonium sulfate and sulfur dioxide.

About the same time Cominco was developing a process, Johnstone and his coworkers at the University of Illinois were developing basic data for the ammonia system. Five major papers were published by Johnstone between 1935-1952 dealing with absorption of sulfur dioxide by ammoniacal solutions and desorption from the absorber effluent (3, 4, 5, 6, 7). Measurements of vapor pressures in the system were made, and methods for regenerating the absorbing solution and recovery of byproducts were studied.

Beginning in 1953, TVA piloted an ammonia absorption process for removal of SO_2 from coal-fired power plant stack gases (8).

Considerable data have been gathered by Chertkov and his coworkers at the NIOGAZ (Scientific Research Institute for Industrial and Sanitary Purification of Gases) in Russia. This work began in the late 1950's and resulted in over 40 papers being published on sulfur oxide recovery, mostly involving ammonia absorption. All phases of the subject have been reported—basic chemical data, mass transfer in absorbers, the autoclave process, and several regeneration schemes. A large portion of the experimental work was done on a pilot scale. Plans are underway for equipping a 240-megawatt boiler with an ammonia absorption and thermal-stripping unit (9).

In Japan, the Showa Denko Company has operated an ammonia absorption test unit (25 MW) on stack gases from an oil burning boiler. Ammonium sulfate was the end product (10).

In 1967, Ugine Kuhlman, Weiritam, and Electricite de France combined to construct and operate a 25-megawatt ammonia absorption unit at an EDF power plant near Paris. In 1969, a thermal-stripping regeneration process was added to the unit. It was closed down after less than 1 year's operation because of high steam consumption in the stripping section (9).

Even with the extensive effort of these early workers, some areas of the ammonia process as applied to power plant stack gas cleanup were not well defined. These areas include: absorber design including multistaging to obtain optimum results, degree of oxidation of sulfites in the absorber loop, effect of fly ash on scrubber operation, absorber product regeneration, and corrosion. Initially, a pilot-plant study program was developed jointly by TVA and EPA to examine the ammonia absorption process. Later, the contract was expanded to include a study of a regeneration process. The initial absorption study was conducted in a pilot plant on unit 3 at TVA's Colbert Power Plant in northwest Alabama. This pilot plant was dismantled to make room for a new electrostatic precipitator on unit No. 3. A new pilot plant was then constructed in another area at Colbert to continue the study of the absorption step with particular emphasis on overcoming the problem of plume formation identified in the earlier study and to study a regeneration scheme.

Several regenerable or semiregenerable ammonia absorption processes have been developed and are, or have been, in full-scale operation. The earliest of these was pioneered by the Consolidated Mining and Smelting Company (Cominco) in Trail, B.C., Canada. The process consists of aqueous ammonia absorption followed by acidification of the sulfite liquor with sulfuric acid to evolve SO_2 and produce ammonium sulfate. The SO_2 is sent to a sulfuric acid plant and the ammonium sulfate is further processed for sale as a fertilizer. The process has been operating continuously and reliably on smelter gas since the mid-1930's and is still in operation. Work on adapting the method to power plant stack gas was carried out by TVA (pilot-plant scale) in 1953-54 (8). The uncertainty of a large market for ammonium sulfate severely limits the applicability of this process in the United States.

Quite similar processes have been developed and are in full-scale operation on sulfuric acid plant tail gases in Czechoslovakia and Romania (11, 12). These processes produce a single end product, such as ammonium sulfate, which may have a limited market.

A cyclic regeneration process producing only SO_2 was postulated and tested in the 1930's by H. F. Johnstone (6). Since concentrated SO_2 is the product, it can be converted into sulfuric acid, liquid SO_2, or elemental sulfur thereby increasing its marketability. Steam stripping was employed to recover SO_2 and to regenerate the ammoniacal solution for reuse in the absorber.

Development of the Johnstone process has been vigorously pursued in the USSR. A 140,000-scfm (60 MW) unit was installed near Moscow in 1952 and operated continuously until 1967 at which time it was dissassembled because the power plant was converted from coal to natural gas. It is reported that the cyclic ammonia process will be installed on a 200-megawatt coal-fired utility boiler in the USSR in 1973. Although the Johnstone process has been shown to be feasible and presupposes no link to a complex fertilizer plant, it possesses some undesirable characteristics. Energy requirements for the process are high, approximately 12 pounds steam per pound of SO_2. Oxidation products may be difficult to purge selectively from the system without loss of active species. The occurrence of undesirable disproportionation reactions in the steam stripper aggravates the oxidation problem.

The regeneration process selected for the EPA-TVA study utilizes an acid ion to decompose the sulfites and release SO_2. In this decomposition of sulfites, it may be possible to regenerate the acid from the salt and thereby avoid the need for disposal of the salt. Such a regeneration process (13) has been known in the fertilizer industry since the 1920's. In this process, the ammonium sulfate is heated to drive off ammonia and produce acidic ammonium bisulfate, which is then used as an acidulant to release SO_2.

In more recent work, an engineering company has incorporated the bisulfate technique in various fertilizer flow sheets (14) and has carried out pilot-plant work for converting ammonium sulfate to bisulfate. The process involves direct heating of the ammonium sulfate with combustion gas. The decomposition reaction is highly endothermic. This work is being expanded currently to a large-scale test program on a scale equivalent to the size required for a 30-megawatt power plant burning 3.5% sulfur coal. Several other research organizations have also worked on the conversion step but in a less extensive way.

Application of the bisulfate technique to regeneration of ammonia absorption liquor in an SO_2 removal process was proposed by Hixson and Miller in 1944 (15). In the bisulfate process, ammonium sulfite-bisulfite liquor is pumped from the absorber to an acidifier-stripper where the following reactions take place:

$$(NH_4)_2SO_3 + 2NH_4HSO_4 \rightarrow 2(NH_4)_2SO_4 + H_2O + SO_2\uparrow \quad (1)$$
$$NH_4HSO_3 + NH_4HSO_4 \rightarrow (NH_4)_2SO_4 + H_2O + SO_2\uparrow \quad (2)$$

Essentially all of the SO_2 is released from the liquor in the acidifier stripper. If a condenser is employed on the off-gas, virtually a 100% stream of SO_2 can be obtained. The resulting stripped solution, containing mainly $(NH_4)_2SO_4$, is sent to an evaporator-crystallizer where the water is removed. Ammonium sulfate crystals are then transported to the decomposer which thermally dissociates the $(NH_4)_2SO_4$ into NH_4HSO_4 and gaseous NH_3. The bisulfate is returned to the acidifier and the ammonia to the absorber, completing the cyclic process. Several modifications of this process are discussed in Appendix A.

The following sections of this report cover the work performed in the two pilot plants. The absorption study in pilot plant No. 1 began in June 1970 and ended in December 1971. The work performed in pilot plant No. 2 and included in this report began with its startup in mid-1972 and extended through June 1973. Additional work using pilot plant No. 2 is planned and will be reported later in a separate volume.

PILOT PLANT NO. 1

(PHASE I)

Equipment and Operation

Construction of the pilot plant No. 1 began in April 1969. Actual plant operation began in June 1970 and extended through December 1971. The pilot plant was installed on TVA's Colbert Power Plant No. 3 unit, a 200-megawatt Babcock and Wilcox, front-fired pulverized coal-burning unit.

A flow diagram of the process is shown in Figure 1. Figure 2 is a pictorial sketch of the pilot plant. Figure 3 shows the location of the pilot plant relative to the power plant ducts and indicates relative size of the equipment.

About 4000 acfm of flue gas at 300°F (equivalent to 1.3 MW) was withdrawn isokinetically immediately after the air preheater and upstream from the mechanical fly ash separators. The gas passed through one of two dust collectors, a gas cooler, and into the absorber.

The absorber shell (32 in x 32 in x 20 ft) consisted of three independent sections plus a gas inlet and outlet assembly. The three sections were removable and contained the various absorber and mist eliminator elements.

Exhaust gas from the absorber was vented into the power plant ductwork or to the atmosphere for observation. A two-stage blower system with a variable-speed drive was used to maintain a constant gas flow under varying degrees of pressure drop.

Process equipment and materials of construction for the pilot plant were selected to approximate a commercial process. Corrosion specimens of various materials were installed at several locations in the system and were periodically removed and evaluated.

The concentration of sulfur dioxide in the gas stream was monitored continually at the tower inlet and outlet and between each of the absorber sections by use of an ultraviolet analyzer. The gas stream was sampled for ammonia, sulfur dioxide, and particulate loadings. Wet chemical analysis procedures were used to determine the quantities of ammonium bisulfite, ammonium sulfite, and ammonium sulfate in the absorber liquor samples. Details of these gas and liquid analtyical procedures are given in Appendix D.

The pilot plant was operated approximately 2000 hours. Parts of the equipment, primarily the blowers and sulfur dioxide analyzer, were also used in a limestone - wet-scrubbing pilot plant. An evaluation of the performance of individual components of pilot plant No. 1 and No. 2 is given in Appendix B.

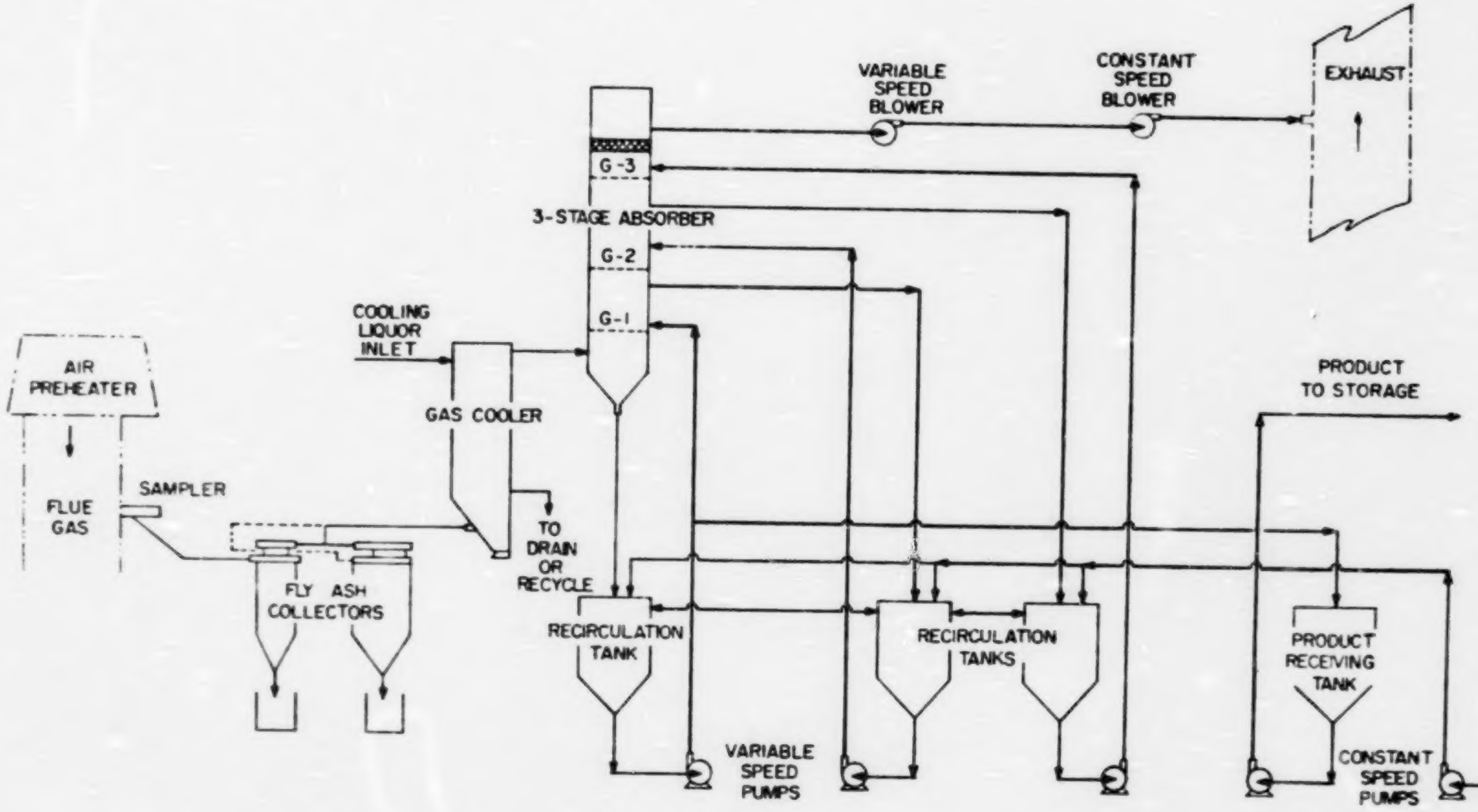

FIGURE 1

FLOW DIAGRAM OF AMMONIA ABSORPTION PROCESS FOR SULFUR DIOXIDE RECOVERY

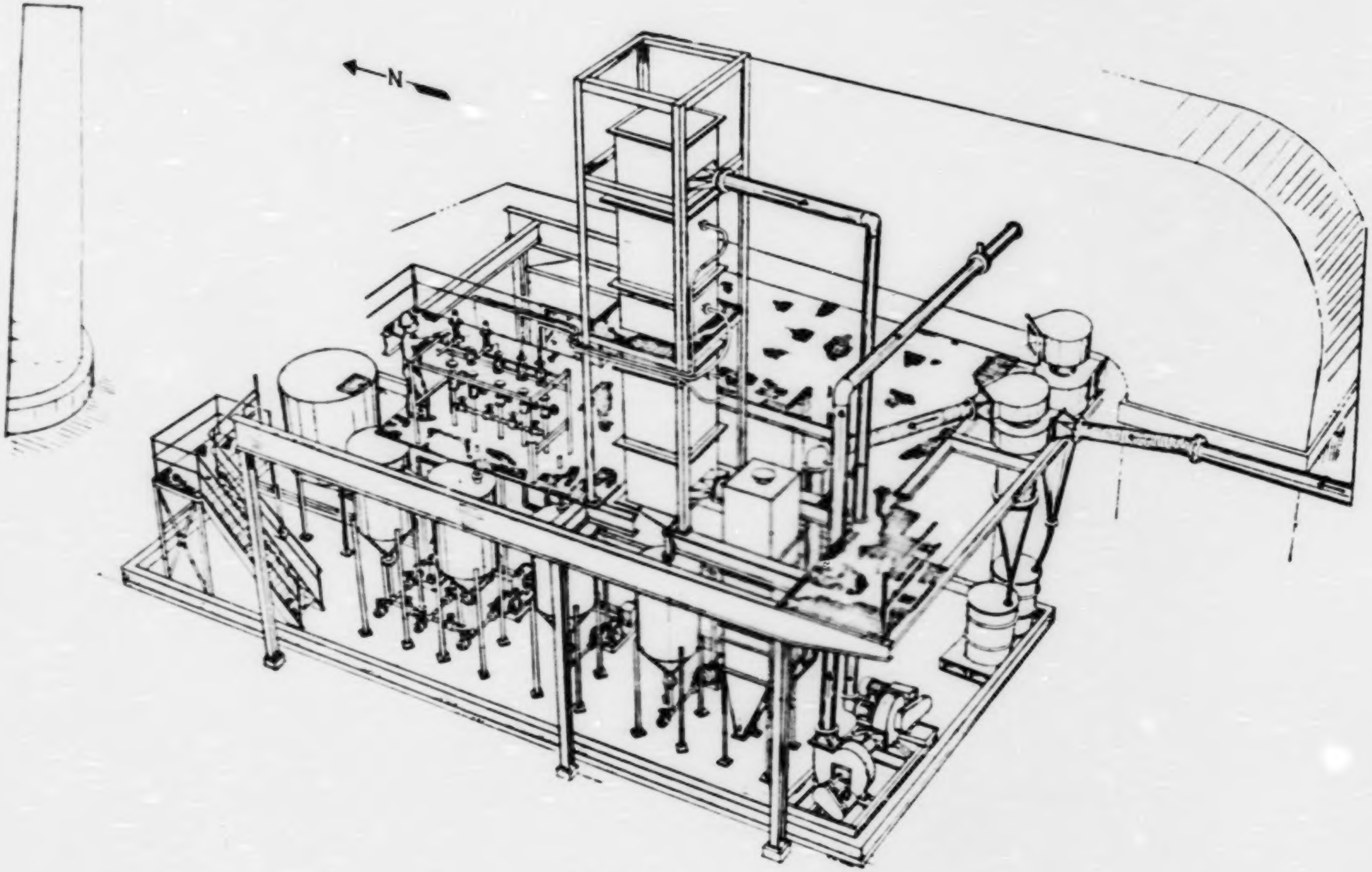

FIGURE 2

PICTORIAL VIEW OF AMMONIA ABSORPTION PILOT PLANT

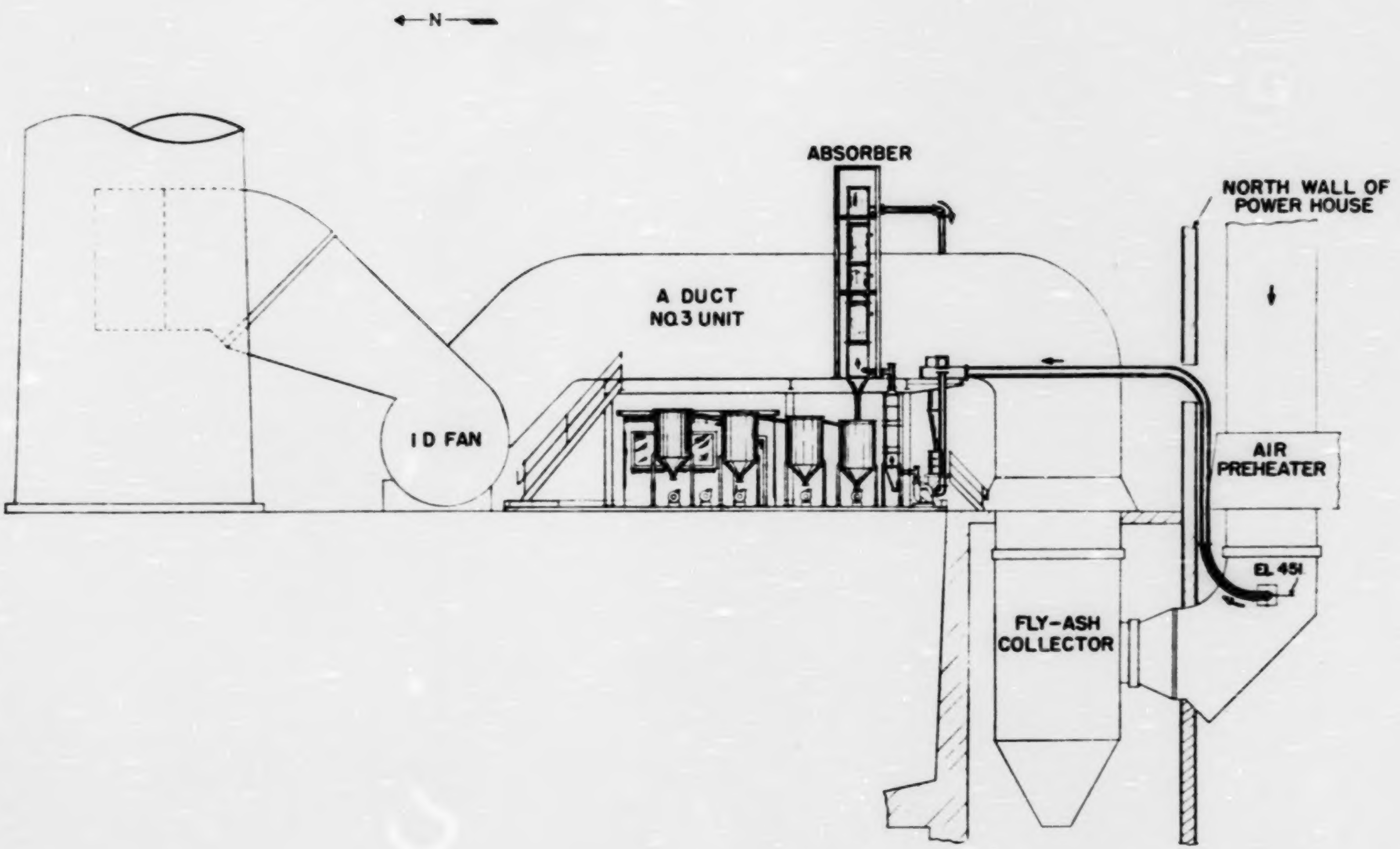

FIGURE 3

LOCATION OF AMMONIA ABSORPTION PILOT PLANT

RELATIVE TO POWER PLANT EQUIPMENT

Study Program and Results

The objectives of this Phase I program were to determine the factors influencing the absorption step in the ammonia-scrubbing process and to obtain data on the following parameters:

1. Sulfur dioxide removal
2. Ammonia loss
3. Fly ash effect on absorber operation
4. Oxidation
5. Heat recovery
6. Corrosion

Sulfur Dioxide Removal

Two separate test programs were conducted in the pilot plant. The first test program examined the effects of the following variables on SO_2 removal and oxidation:

Variable designation	Description	Range to be tested
x1	Inlet flue gas temperature, °F	180 to 210
x2	Fly ash loading of inlet flue gas, gr/scf	0.3 to 3
x3[a]	C_A' of forward feed solution	8 to 15
x4[b]	S/C_A' of forward feed solution	0.65 to 0.72
x5	Ammonium sulfate in forward feed, gm/l	4 to 110
x6	Flow rate of forward feed liquor, gpm	3 to 5
x7	Flow to top of scrubbing stage, % of x6	6 to 12

[a] C_A' is the mols of ammonia in the form of ammonium sulfite and bisulfite per 100 mols of total water.

[b] S/C_A' is a mol ratio of SO_2 present as ammonium sulfite and bisulfite to the ammonia present as ammonium sulfite and bisulfite.

With this moderately large group of variables, it was decided to conduct a highly fractionated 2^n test program consisting of 18 tests—16 points on the hypercube and 2 center points. In this type of test program, unambiguous results can be obtained on the linear effect of each individual variable, but the interrelations between variables are masked, assuming that higher order interactions (three or more variable combinations) are negligible. This is known as a Resolution IV design.

The original levels specified for the independent variables were not exactly achieved; however, the consistency of levels achieved was such that a simple analysis of variance (Table 1) was performed for the percentage of SO_2 removed. The actual data are tabulated in Appendix C.

The variables having a significant linear effect on the SO_2 removal at the levels tested and the percentages of variation explained were:

Variable designation	Description	% variation explained
x4	S/C_A' of forward feed solution	74.5
x1	Temperature of the inlet flue gas	3.9
x3	C_A' of forward feed solution	2.8
x5	Ammonium sulfate concentration, gm/l	1.5

The following tabulation gives a breakdown of the mean difference of the significant linear effects which were derived from the first tabulation shown on page 12.

Variable	Mean difference in percentage SO_2 removal (avg of high setting − avg of low setting)
Inlet flue gas temperature (x1)	3.4
C_A' of forward feed solution (x3)	−2.9
S/C_A' of forward feed solution (x4)	−14.9
Ammonium sulfate concentrations (x5)	2.1

Several important observations were made from the analysis. First, increasing the temperature of the inlet flue gas increased the SO_2 removal. This was unexpected. However, further examination of the data showed that the higher inlet flue gas temperature required that more makeup water be added to the system. The additional makeup water was added to the third stage, thereby reducing C_A' and S/C_A', hence improving the scrubbing potential. These observations and conclusions were supported by a computer simulation model developed for the Environmental Protection Agency by Jonathan Earhart.

Next, increasing the sulfate concentration also improved the removal. Johnstone's equations for the vapor pressure of SO_2 over solutions indicate that the sulfate level does not alter the SO_2 vapor pressure; however, Chertkov's equation shows that increasing sulfate concentration increases the SO_2 vapor pressure over solutions. The effect of sulfate in the statistical analysis,

TABLE 1

ANALYSIS OF VARIANCE FOR PERCENTAGE OF SULFUR DIOXIDE REMOVED

Source	Sum of squares	Degrees of freedom	Mean square	F-ratio (1) $F_{1,8,.05}$=5.3177
Mean	123728	1		
Linear (total)	994.5	7		
x1	45.9	1	45.9	14.9268
x2	3.1[a]	1		
x3	33.1	1	33.1	10.7642
x4	885.1	1	885.1	287.8374
x5	18.1	1	18.1	5.8862
x6	7.6[a]	1		
x7	1.6[a]	1		
2-factor interaction	185.6	7		
x2x4[b]	60.1	1	60.1	19.5447
x4x5	85.6	1	85.6	27.8374
x3x4	7.6[a]	1		
x4x1	27.6	1	27.6	8.9756
x4x6	1.5[a]	1		
x2x7	0.1[a]	1		
x4x7	3.1[a]	1		
Residual (higher order interactions)	7.6	1		
Pooled error	24.6	8	3.075	
Total	124915.7	16		

[a] Sum of squares used for pooled error sum of square (1) F - ratio 5.3177 significant for $\alpha = 0.05$ with 1, 8 degrees of freedom.

[b] Only one pair listed- -each pair has two other aliases.

while significant ($\alpha = 0.05$), is not compelling. Also, the levels of sulfate concentration were not widely separated. The lack of significance of the forward feed rate and the percentage of forward feed to the top stage on SO_2 removal indicated that, in the next test program, the levels of these variables should be altered to higher and lower levels.

Since the temperature of the flue gas showed a positive direction, it was decided to expand the temperature range to approximately 180° to 300°F.

The level of the the fly ash in the incoming flue gas did not affect the SO_2 removal over the range tested (0.3 gr/scf to 5 gr/scf) and it presented no mechanical problems. Therefore, the level of fly ash was disregarded as a variable of any impact.

Lastly, the presence of significant two-factor interaction and the observations and conclusions of the statistical analysis, paired with the chemical engineering and computer simulation work, led to the second experimental test program.

The second experimental test program was a half-replicate of a 2^5 factorial test. The independent variables were as follows:

1. Inlet flue gas temperature, °F
2. Flow rate of forward feed solution, gpm
3. C_A' of forward feed solution
4. Sulfate concentration of forward feed solution, gm/l
5. Flow to top stage, % of variable 2

In addition, it was decided that instead of adding ammonia to the forward feed solution to maintain a constant forward feed liquor, that no ammonia be added, thereby getting a response of SO_2 removal with varying S/C_A' for each set of 16 test conditions. The run was terminated when the SO_2 removal dropped to approximately 40%. The actual data are tabulated in Appendix C.

The variables and their respective levels tested in the second test program are listed in the tabulation on the following page. The responses that were analyzed as a function of the independent variables were SO_2 removal and ammonia loss.

Because of the extreme nonlinearity of the responses, the analysis of the data collected in the second test program was not so straightforward as the first test program. The first attempts at a simple factorial analysis were unsatisfactory because of the large residual and will not be presented. In an attempt to describe the experimental results, it was decided to base all work on the compositions of the forward feed solution and incoming flue gas.

Independent variables for the second test program are shown below.

Variable designation	Description	Range to be tested
Split	The percentage of feed liquor directed to the top tray	10 to 20%
FF	Forward feed flow rate	2 to 5 gpm
$[NH_3]$	Effective ammonia concentration; i.e., $\frac{[\text{mols } NH_4^+ - 2(\text{mols } SO_4^=)] \times 100}{\text{mols } H_2O}$	5 to 10
$[SO_4]$	Sulfate concentration	Low to saturated
T	Temperature of incoming flue gas	225° to 300° F

The unit of mol/min (ft^2 of absorber cross-sectional area) was selected in an attempt to analyze the data and provide scale-up parameters. The analysis of the data showed that the mol/min (ft^2) of $(NH_4)_2SO_3$ in the forward feed solution was the largest single controlling variable on SO_2 removal. A nonlinear model was constructed in an attempt to adequately describe the SO_2 removal as a function of the following variables:

Z_1. Mol/min(ft^2) of sulfur as $(NH_4)_2SO_3$ divided by mol/min(ft^2) of incoming SO_2 at 125° F.

Z_2. Mol/min(ft^2) of sulfate sulfur in the forward feed.

Z_3. Mol/min(ft^2) of ammonia as sulfite and bisulfite in the forward feed.

The following model describes the SO_2 removal for the second screening test runs.

$$\text{Percent } SO_2 \text{ removal} = \frac{K \times Z_1 \times 100}{(K/2)^2 + (Z_1)^2} \qquad (3)$$

Where

$K = 1.62 + 0.27Z_2 + 0.6Z_3$, and

Z_1, Z_2, and Z_3 = values shown above

The standard error of equation (3) is approximately 4% SO_2 removal. The temperature of the inlet flue gas was also a significant variable, but it has been deleted since its effect is to increase the SO_2 removal approximately 3% when the inlet flue gas temperature is raised to 290°F. The behavior of equation (1) is illustrated in Figures 4 and 5. From these figures it can be seen that increasing the sulfate concentration reduced the SO_2 removal, but the effect is dampened at the higher levels of Z_1—mols/min(ft^2) of sulfur as $(NH_4)_2SO_3$. This is in agreement with Chertkov's equation for the effect of $(NH_4)_2SO_4$ on the vapor pressure of SO_2 over solutions.

Ammonia Loss

The ammonia loss from the scrubber was controlled by the solution composition at the top stage. In order to maintain the ammonia loss below 50 ppm and the SO_2 below 250 ppm, it was found that the pH of the solution to the top stage must be below 6.1. Analysis of pH versus S/C_A' of the second screening test runs led to the following equation:

$$pH = 9.234 - 0.023C_A' - 0.002(SO_4) - 4.222\ S/C_A' \quad (4)$$

Where

C_A' = ammonia concentration as $(NH_4)_2$ and NH_4HSO_3 – (mols/100 mols H_2O)

SO_4 = sulfate sulfur concentration, gm/l

S/C_A' = ratio of mols of sulfur $[(NH_4)_2SO_3$ and $NH_4HSO_3]$ to mols of ammonia $[(NH_4)_2SO_3$ and $NH_4HSO_3]$

Table 2 is the analysis of variance for equation (4).

TABLE 2

ANALYSIS OF VARIANCE FOR pH

Source	Sum of squares	Degrees of freedom	Mean square	F-ratio $F_{3,161,0.01} = 3.7816$
Regression	42.00	3	14.00	1944.4
Residual	1.159	161	.0072	
Total	43.159	164		

Variable	Coefficient	t–statistic
C_A'	– .023	7.3[a]
SO_4	– .002	10.8
S/C_A'	–4.222	75.3

[a] Each t–statistic is significant at α = 0.01 or less.

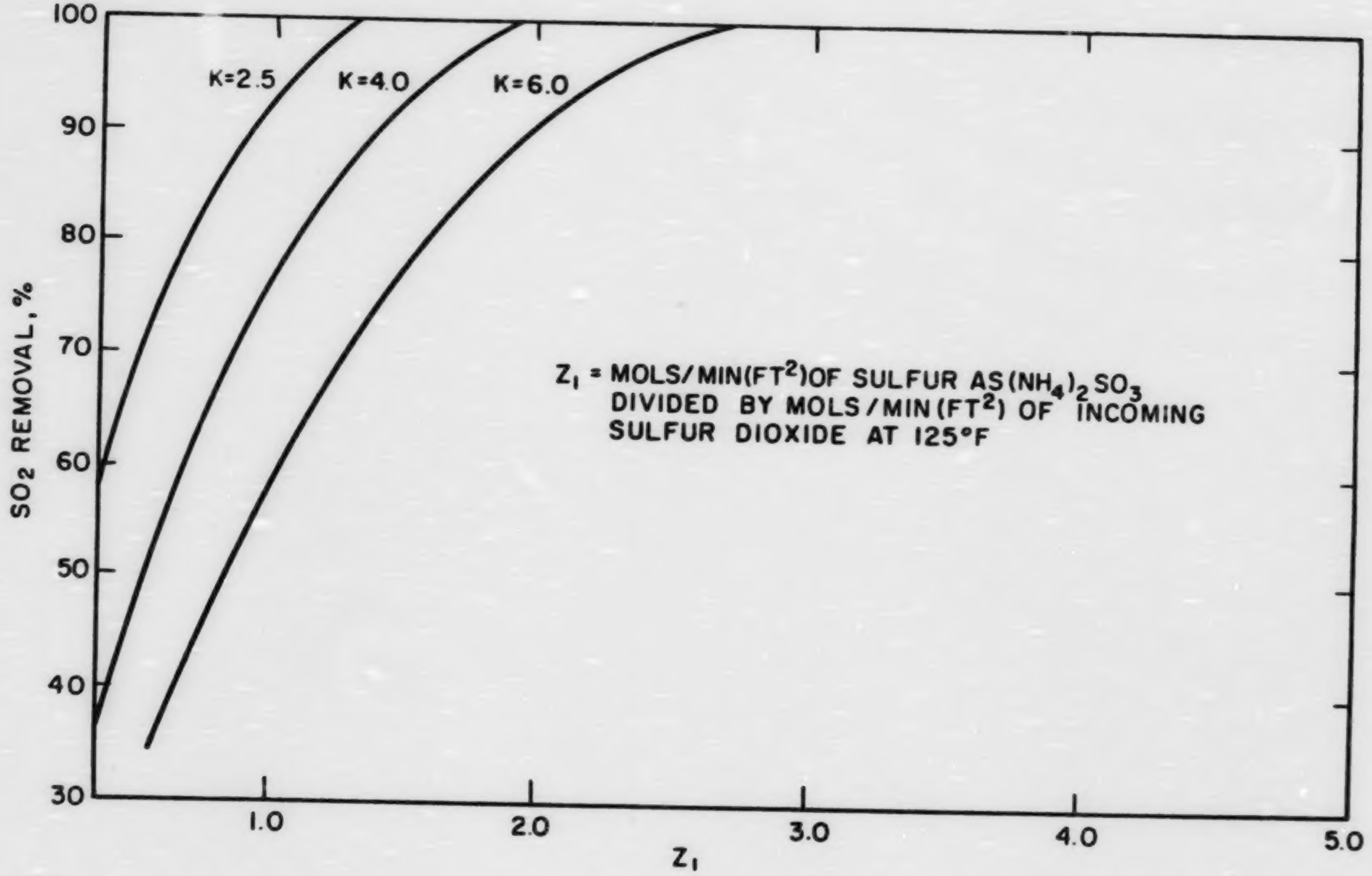

FIGURE 4

Sulfur Dioxide Removal vs Z_1

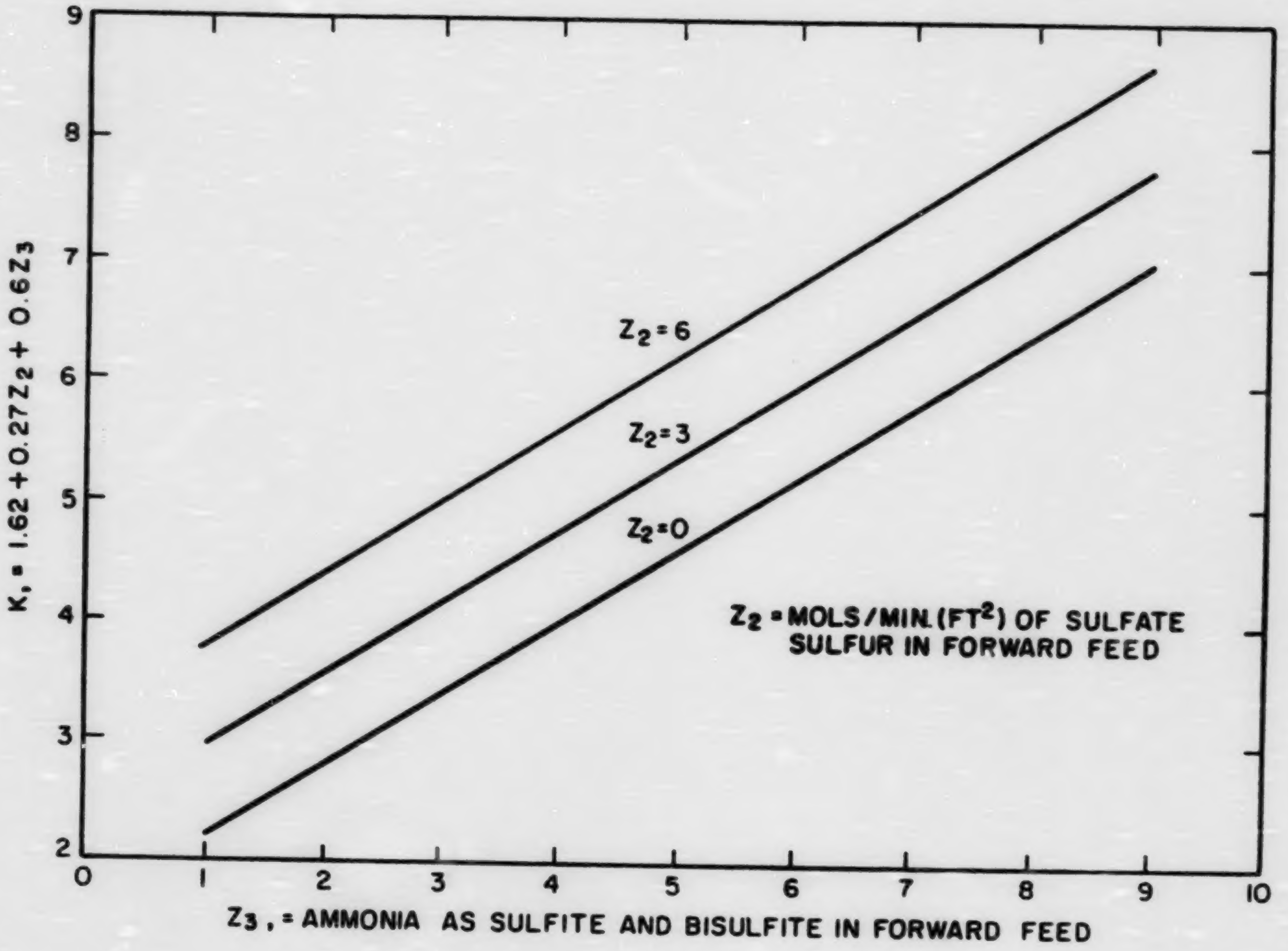

FIGURE 5

K vs Z_3

Each of the variables in equation (4) is highly significant ($\alpha = 0.01$ or less). The S/C_A' ratio has the largest effect on the pH. If C_A' and SO_4 are set at their midpoints (i.e., $C_A' = 7$ and $SO_4 = 50$), then equation reduces to:

$$pH = 8.973 - 4.222\ S/C_A' \qquad (5)$$

Both Johnstone and Chertkov have presented equations for S/C versus pH. Johnstone's equation is:

$$pH = 9.2 - 4.62\ S/C$$

Chertkov's equation is:

$$pH = 8.88 - 4.0\ S/C$$

The equation derived from the TVA-EPA program falls between the above two equations and also includes the effects of ammonia and sulfate concentrations. As with Johnstone's and Chertkov's equations, the validity of equation (4) is limited to the region of testing.

Oxidation

Oxidation data obtained during both test programs were very scattered. This resulted from taking the difference between two large numbers. As a result of the scatter in the data, little definite work could be done; however, the S/C_A' ratio did show an effect on oxidation. The increase of S/C_A' did increase oxidation. The following tabulation lists the average percent oxidation and the average S/C_A'.

S/C_A' of forward feed	Percent oxidation
0.65	3
0.69	10
0.72	23

The amount of oxidation in subsequent test work in which the scrubber was run under generally similar conditions averaged about 13% with an S/C_A' of approximately 0.65, which is in reasonable agreement with statistical test program results.

Heat Recovery

The stack gases from any power plant wet-scrubbing process must be reheated to increase its bouyancy enough to disperse the SO_2 and dust. Heat capacity data were obtained to permit calculation of the heat input required for reheating the scrubbed gases to an acceptable temperature (175°F). Data were also obtained on the overall heat transfer coefficient for a standard tube-and-shell type of heat exchanger for indirectly reheating the gases.

Flue Gas Heat Capacity: Data on the heat capacity were taken before and after the flue gas was scrubbed with the ammoniacal liquor. Flue gas at a temperature of about 290°F from the coal-fired boiler entered the shell side of a tube-and-shell type heat exchanger and was cooled to about 200°F by countercurrent flow of water on the tube side. Calculations based upon these data indicated an inlet flue gas heat capacity of 0.260 Btu/lb(°F). This value agrees with the value cited in literature (16) of 0.255 Btu/lb(°F).

The heat capacity of the scrubbed gas was calculated to be 0.269 Btu/lb(°F). This value was computed by adjusting the inlet gas value to compensate for the increased water content of the scrubbed gas. The literature value (16) for this gas is 0.263 Btu/lb(°F). A 500-megawatt plant would require about 66 million Btu per hour to reheat the saturated gas from 125° to 175°F. This is equivalent to about 1-1/2% of the coal required to generate the 500 megawatts.

Overall Heat Transfer Coefficient, Uo: The overall heat transfer coefficient of the flue gas tube-and-shell heat exchanger was calculated on the basis of temperature and flow measurements of the streams entering and leaving the heat exchanger. The exchanger, manufactured by Thermal Transfer Corporation, consisted of three sections. Each section contained 224 square feet of heat transfer surface made from 3/4-inch mild steel tubes. The direction of gas flow was perpendicular to the tubes. The flue gas entered the shell side; cooling water flowed countercurrently on the tube side. The manufacturer's stated Uo for the clean heat exchanger was 11.3 Btu/hr(ft^2)(°F). The Uo was not measured when the new heat exchanger was originally installed. After about 2 months of operation, the heat transfer data indicated a Uo of 2.9 Btu/hr(ft^2)(°F). After 18 months' operating time, the Uo was 2.7 Btu/hr(ft^2)(°F), essentially unchanged from the earlier finding. The indicated decrease in the Uo from the specified new condition was apparently caused by fly ash buildup and corrosion products that could not be removed from the tube surfaces by use of soot blowers provided with the heat exchanger. The soot blowers might have cleaned the surfaces if the design steam pressure of 600 psig had been available. Steam at only 350 psig was available at the site.

Corrosion

Twenty different materials of construction, metallic and nonmetallic, were tested for corrosion and erosion throughout the scrubber system using the standard ASTM method. Coupons of the materials were installed in the flue gas ducts, absorber, recirculation tanks, and pipelines. A detailed listing of all materials tested, test location, exposure time, and evaluation is presented in Appendix F.

Abrasion from fly ash was probably more serious than corrosion in the inlet flue gas ducts. The flue gas contained up to 5 grains of fly ash per cubic foot and had a velocity of approximately 60 ft/s. The stainless steels tested were satisfactory while mild steel deteriorated at an excessively high rate. Mild steel ducts are used for similar service in large steam plants and give good service because a coating deposits inside the large ducts and protects the metal. Most of the nonmetallic materials failed because of high temperature (280°-310°F) or abrasion.

Several types of stainless steel and special alloys showed good resistance to corrosion in the wetted areas (absorber, recirculation tanks, pipelines, and exhaust duct). Mild steel was unsatisfactory in all wetted areas. Most nonmetallic materials were rated as satisfactory where temperature limitations were not exceeded.

Plume

A major problem associated with the ammonia absorption process is the emission of a dense plume of water vapor and ammonia salts. The severity of the plume problem necessitated the expenditure of a large portion of the test work at pilot plant No. 1 in an effort to determine the operating factors affecting plume emission. Unsuccessful attempts were made to determine the operating conditions that caused the plume formation.

PILOT PLANT NO. 2

(PHASE II)

From the results obtained by operating pilot plant No. 1, a decision was made to expand the study of the ammonia absorption process to include the regeneration step. In addition, a concerted effort was planned to overcome the problem of plume emission from the absorption step.

Equipment and Operation

The new pilot plant was designed to treat 4000 acfm of flue gas at 300°F. Stainless steels (304 and 316), rubber, and Teflon were used in all wetted sections for corrosion protection. The gas ducts were mild steel. In the following discussions, the plant is divided into the absorption and regeneration sections. Pilot plant No. 2 was operated for approximately 1100 hours.

Absorption

The absorption section is shown in Figure 6. The absorber was the three-stage, marble-bed unit (Environeering, Inc., Hydro-Filter) which was used in the previous ammonia absorption study. The three absorber stages could be operated to maximize the $SO_2:NH_3$ ratio in the product liquor while limiting the SO_2 and NH_3 content of the exit gases to 250 and 50 ppm, respectively.

The source of the pilot-plant flue gas was downstream from the electrostatic precipitator on unit No. 4 at TVA's Colbert Power Plant. Most of the fly ash was removed in the precipitator; however, the remaining fly ash (up to 0.5 gr/scf) entered the pilot-plant absorber. A portion of the ash was removed and accumulated in the absorber solution at a rate of 1 to 10 pounds per hour, depending on the efficiency of the precipitator.

Most of the fly ash accumulated in the absorber product storage tanks F-5 and F-6. (Each of the storage tanks had a capacity for approximately 24 hours' absorber operation.) Periodically, the settled material was purged from the system. In future work, studies of fly ash separation will be made.

Regeneration

The regeneration section shown in Figure 7 was designed to process liquor produced in the absorber section. The pilot-plant regeneration process was designed to include the following steps.

1. Acidulation of the absorber product with ammonium bisulfate melt to release SO_2 and form ammonium sulfate.

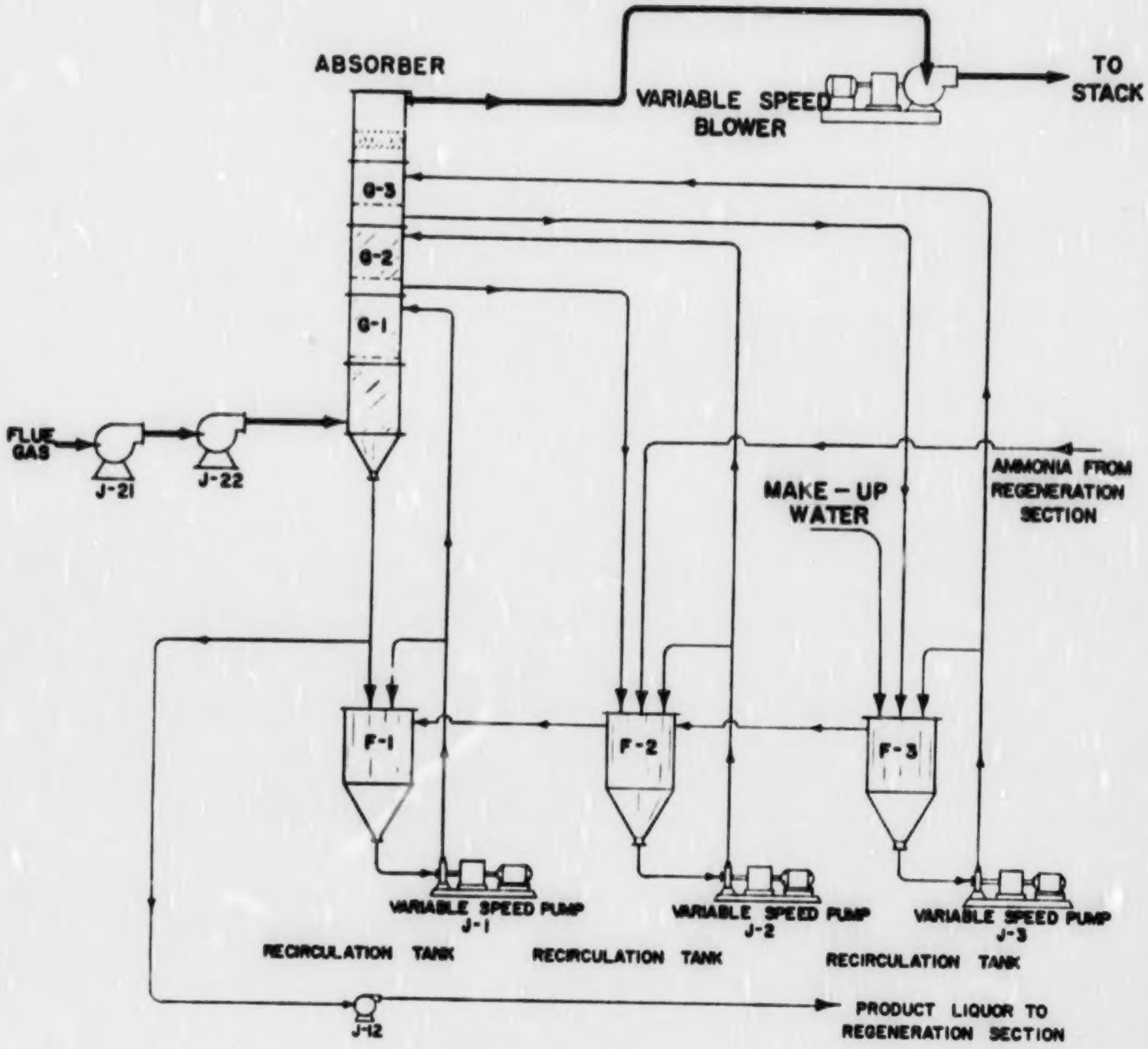

FIGURE 6

ABSORPTION SECTION

AMMONIA ABSORPTION - AMMONIUM BISULFATE REGENERATION PROCESS

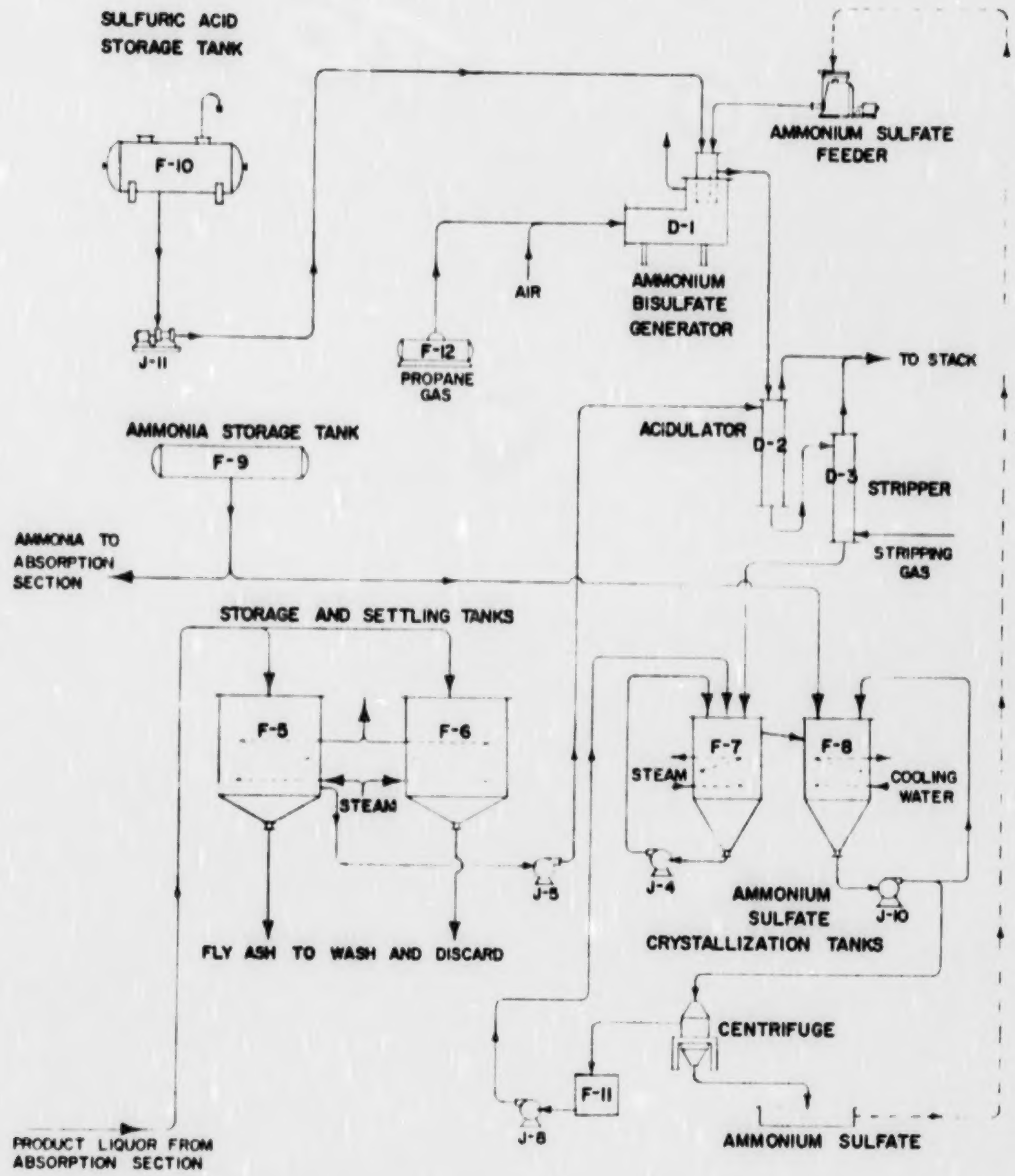
SULFURIC ACID STORAGE TANK
F-10
J-11
F-12
PROPANE GAS
AIR
D-1
AMMONIUM BISULFATE GENERATOR
AMMONIUM SULFATE FEEDER
TO STACK
ACIDULATOR
D-2
D-3
STRIPPER
STRIPPING GAS
AMMONIA STORAGE TANK
F-9
AMMONIA TO ABSORPTION SECTION
STORAGE AND SETTLING TANKS
F-5
F-6
STEAM
J-5
FLY ASH TO WASH AND DISCARD
F-7
F-8
STEAM
COOLING WATER
J-4
J-10
AMMONIUM SULFATE CRYSTALLIZATION TANKS
CENTRIFUGE
F-11
J-8
AMMONIUM SULFATE
PRODUCT LIQUOR FROM ABSORPTION SECTION

FIGURE 7

REGENERATION SECTION

AMMONIA ABSORPTION - AMMONIUM BISULFATE REGENERATION PROCESS

2. Stripping of the released SO_2 from the ammonium sulfate solution.

3. Crystallization and separation of ammonium sulfate from the mother liquor.

4. Generation of ammonium bisulfate for the acidulation step by heating a 1:1 mol ratio of H_2SO_4 and ammonium sulfate.

The acidulation was accomplished in a vessel made from a 6-foot section of a 12-inch stainless steel pipe. The vessel was coated internally with DuPont's TFE Teflon for corrosion protection. Mixing of the incoming absorber liquor and ammonium bisulfate was accomplished in a cone mixer in the upper part of the acidulator. Released SO_2 flowed from the acidulation and joined the effluent from the stripper vessel. The overflow from the acidulator to the stripper could be raised or lowered to vary the retention time of material in the acidulator from 0 to a maximum of 30 minutes.

The Teflon-lined stripping vessel was 1 foot in diameter by 6 feet high and contained a 4-foot section of 1/2-inch ceramic Raschig rings. Acidulated liquor entered the top of the vessel and flowed countercurrently to a stream of stripping gas entering the vessel near the bottom. In the pilot plant, provisions were made to use either steam, air or scrubbed flue gas as the stripping gas.

Ammonium sulfate solution from the stripping vessel flowed by gravity to crystallization tank F-7 where the water evaporated. The concentrated solution then flowed to F-8 where cooling and crystallization occurred. The ammonium sulfate crystals were separated from the mother liquor.

In a completely closed-loop ammonium bisulfate regeneration scheme, all the ammonium sulfate produced in the acidulation step is thermally decomposed. The resulting ammonium bisulfate is fed to the acidulation step and the ammonia was returned to the absorption section. In this pilot-plant study, the thermal decomposition stage was omitted and the acid ion was furnished by sulfuric acid. Ammonium bisulfate will be the source of the acid ion later. The required ammonium bisulfate will be generated by heating a 1:1 molar mixture of sulfuric acid and ammonium sulfate. The sulfuric acid and the ammonium sulfate will be fed separately and continuously to the ammonium bisulfate generator D-1, a Teflon-lined stainless steel vessel. Here, sufficient heat will be added to the acid-ammonium sulfate mixture to evaporate the water added with the acid and to bring the mixture to about 350°F. The ammonium bisulfate melt will then be fed to the acidulator.

Since ammonium sulfate was not decomposed during this study, no ammonia was available from the regeneration section. The makeup ammonia was fed from the ammonia storage tank F-9 directly to the absorption section. Provisions will be made later to simulate ammonia recovery from a stream of off-gases from a thermal decomposition process.

Vent System

The exit flue gas is vented to the atmosphere for plume observation. The recovered SO_2 from the acidulator and stripper was vented into the power plant stack. The storage tanks containing ammoniated solutions were vented to the absorber or to the stack.

Instrumentation

The pilot plant is instrumented throughout so that all pertinent liquid and gas flows are monitored and values are recorded. All signals are electrically transmitted from the sensing elements to the recorder-controllers.

The gas flow through the absorber system is monitored using a flange orifice in the duct leaving the absorber. A differential pressure (d/p) cell (The Foxboro Company) senses the pressure differential across the orifice and sends a signal to a recorder-controller on the pilot-plant instrumentation board. Any deviation from the preset values on the controller-recorder causes a signal to be sent to the variable-speed drive mechanism on the induced-draft blower (J-23) to correct the deviation. This arrangement assures that a constant gas flow through the absorber system is maintained.

Sulfur dioxide levels in the gas to the absorber and after each stage are monitored using an ultraviolet analyzer (DuPont's 400 Photometric Analyzer). The analyzer has three ranges of SO_2 values: 0-4000, 0-1000, and 0-100 ppm full-scale reading. The sample selection is changed manually from station to station to avoid the possibility of leaks from an automatic sample sequencing system. Periodic checks by wet-chemical methods confirmed the analyzer readings.

A smoke detector is used to monitor the opacity of the plume at the stack exit. The instrument, manufactured by Photomation, Inc., used a light source and a photocell to measure the plume opacity. The digital readout is in Ringlemann units.

Gaseous ammonia was metered to the system as required with a Foxboro differential pressure cell coupled with a recorder-controller and a flow control valve. Liquid flows are sensed by magnetic flowmeters which send electronic signals to recorder-controllers. The required flows of recirculating liquor to the first two absorber stages are maintained by variable-speed pumps J-1 and J-2. Variable-speed pumps are used for flow control instead of valves because fly ash removed in the bottom stages could cause plugging and erosion of control valves. Automatic flow control valves are used to control the flow of the remaining liquid streams.

Temperatures throughout the system were sensed with thermocouples and recorded on strip charts in the control room.

See Appendix B for an evaluation of equipment performance for pilot plant No. 1 and No. 2.

Study Program and Results

Problem Areas

Plume: The most severe problem encountered during the study of the ammonia absorption process was the formation of a dense persistent plume. A typical plume emitted during routine pilot-plant operations with no gas reheat (exit temperature is approximately 125°F) is shown in Figure 8. The plume was formed during operation using three absorption stages, no prior humidification, and while producing a liquor with a C_A of about 10 and an S/C_A of 0.8. The sulfur dioxide removal efficiency under these conditions was typically about 90%. Efforts to reduce or eliminate the plume through manipulation of the pH of the absorber liquor and the addition of a humidification step ahead of the absorber did not significantly reduce the plume opacity. Under these conditions, the steam plume may have masked any reduction in the ammonia-based plume. Adding a wet-electrostatic precipitator after the absorber failed to produce significant results at the normal gas flow rate, 2600 scfm. (The precipitator was found to be 50% efficient in removing the particulate mass at this flow rate—15 ft/s shell velocity through the precipitator.)

Chemical and petrographic analyses of the plume collected in an impaction sampler (Brinks mass sampler) indicated that the major fraction of the ammonia-sulfur salt was ammonium sulfate. It is probable that the particulate was formed in the vapor phase as ammonium sulfite and then oxidized to the sulfate form in the sampler. A portion of the particulate has been analyzed as ammonium chloride. (The coal used during these tests normally contained 0.1-0.2% chlorides.) Tests showed that a water wash ahead of the absorber materially reduced the chloride content of the gas entering the absorber.

Personnel from the Southern Research Institute of Birmingham, Alabama, determined the fume mean particule size to be 0.25 micron with 10^7 particles/cm^3 in the size range of 0.005 to 0.5 micron.

Solids Separation: Other problems identified in the pilot-plant program are not so visible as the plume problem but they may prove to be as difficult to solve. These are problems of fly ash separation and ammonium sulfate separation. Most of the fly ash settled in the absorber product storage and settling tanks during the 24 hours of retention. However, the small quantity in the supernatant liquor from the tanks may be sufficient to adversely affect the production of crystalline ammonium sulfate further downstream in the process. Also,

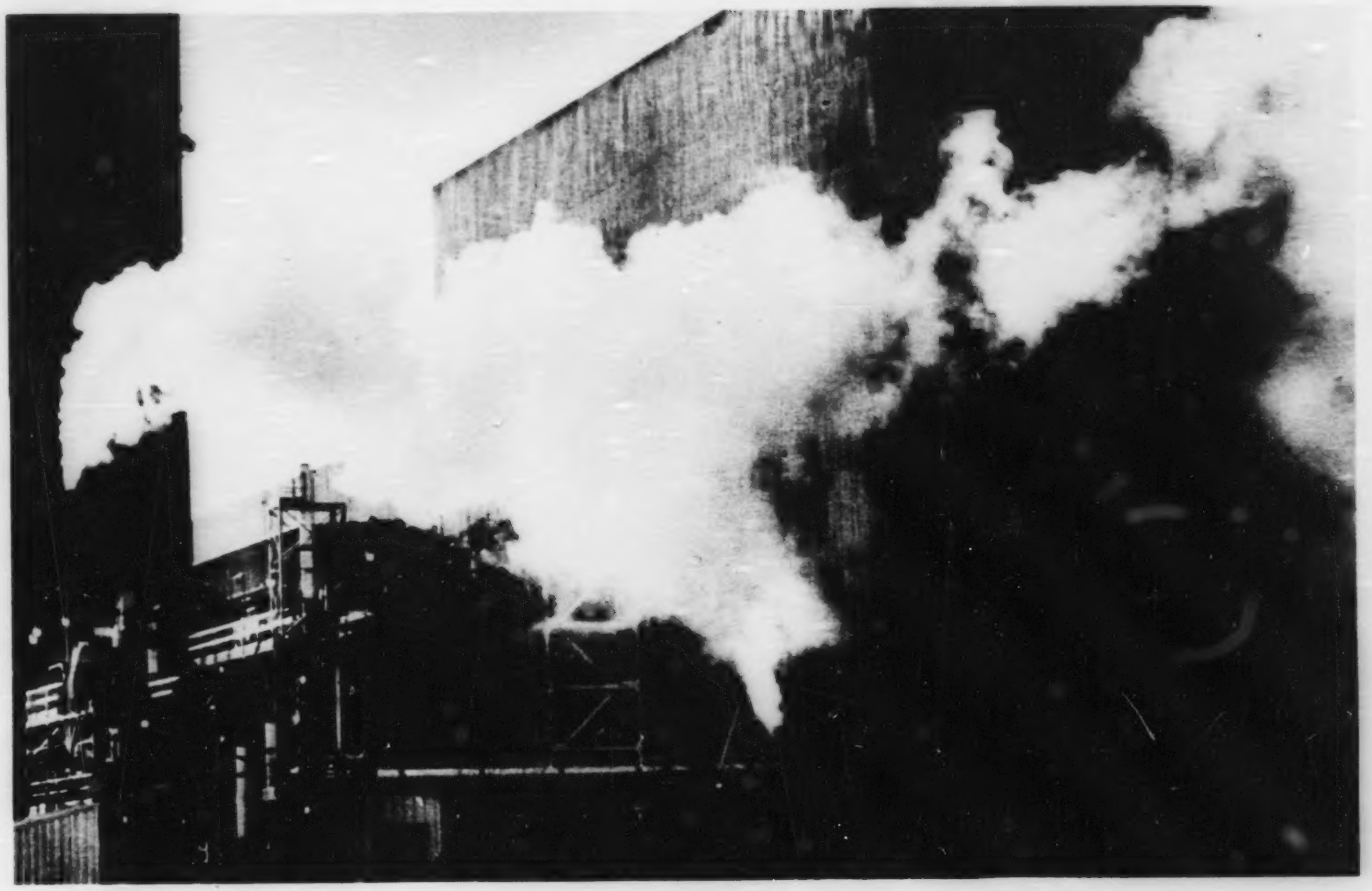

FIGURE 8

A Typical Plume from the Ammonia Absorption Pilot Plant During Routine Operation

(Product from Absorber: $C_A = 10$, $S/C_A = 0.8$) No Reheat

The fly ash which contains iron may catalyze the decomposition of ammonia during thermal decomposition of ammonium sulfate. Attempts to remove the product liquor from the settled fly ash by filtration in a tub filter failed because of blinding of the filter media. The fly ash was settled from absorber product liquor which had C_A values of approximately 10 and contained from 10 to about 30% by weight ammonium sulfate. The blinding was caused by gelatinous, thixotropic material containing finely divided fly ash and needle-like crystals of ferrous ammonium sulfite which precipitated from the absorber solution. The dissolved iron contained in this compound probably came from the fly ash. The quantity of iron dissolved in the solution is small—on the order of 0.01 gm/l. Use of filter aids and precoats on various types of filter media failed to prevent blinding.

An equipment company specializing in solids separation made filtration tests on the absorber product liquor containing fly ash and also on the mud from the bottom of the settling tanks. Drum filters with filter aids were recommended for both materials.

Separation of ammonium sulfate crystals from the acidulated and concentrated liquor in the regeneration loop, though difficult, may be easier than fly ash separation. Liquor concentration and crystal growth occur by evaporating water from the solution in a tank at atmospheric pressure. Crystal growth cannot be controlled in this equipment and attempts to separate the small crystals in the pilot-plant centrifuge and drum filter failed. Petrographic analysis indicated that ferrous ammonium sulfite was present in the material blinding the separation equipment the same as in the fly ash separation tests.

Bench-scale work using solutions from the pilot-plant operation produced much larger crystals than those produced in the pilot plant. The ferrous ammonium sulfite did not cement together the larger crystals produced in the bench-scale work. Filtration rates of over 200 gal/hr(ft^2) were obtained. The use of an evaporator-crystallizer is expected to produce the required crystals although the small amount of fly ash in the solution may influence the design (and cost) of the unit. The equipment manufacturers were contacted concerning the sulfate crystal growth and separation and they were of the opinion that the standard sulfate crystallizer equipment would be sufficient. However, all stated that they could not guarantee this equipment without making tests using the actual solution containing fly ash.

Once adequate crystals of proper size are produced, separation could be accomplished by standard methods of filtration and centrifugation used in the ammonium sulfate industry.

Pilot-Plant Test Results

Routine Operation: Performance of the pilot plant in removing SO_2 from the flue gas and in subsequently releasing the absorbed SO_2 has been good. Data from a typical pilot-plant run when producing an absorber liquor with a C_A of 10 and an S/C_A of 0.8 are presented in Table 3. The ammonia required to react with the SO_2 was added to the second-stage absorber loop (F-2 tank). Approximately 90% of the SO_2 was removed under these conditions. Approximately 13% of the absorbed SO_2 was oxidized to ammonium sulfate.

The regeneration loop was operated using sulfuric acid to acidify the liquor from the absorber section. Typical data from these tests are shown in Table 4. Sulfuric acid was used for acidulation instead of ammonium bisulfate because no ammonium sulfate crystals were available from the pilot plant for production of the bisulfate. Clarified liquor from the absorber section was pumped to the acidulator at approximately 0.4 gpm, the rate the liquor is produced in the absorber. Sulfuric acid was pumped to the acidulator at a rate of 1.2 mols of acid ion per mol of sulfite and bisulfite sulfur in the feed liquor. Approximately 85% of the sulfur dioxide present as the sulfite or bisulfite in the feed liquor was released from the acidulator. The liquor containing the remaining SO_2 flowed to the stripper. Approximately 83% of the residual SO_2 was removed by stripping with 12 cfm of air. The overall removal efficiency of the combined acidulator and stripper was 97%.

The acidulated and stripped liquor flowed to the evaporation tank F-7. The liquor was concentrated to about 45% ammonium sulfate by weight and then cooled in tank F-8 to near 100°F to precipitate crystalline ammonium sulfate. As noted earlier, the ammonium sulfate could not be separated from the mother liquor in the pilot-plant equipment.

Double-Alkali Tests: Production of liquors with low C_A is uneconomical for use in the ammonium bisulfate regeneration process because of the energy requirements to concentrate the solutions in the regeneration section. However, scrubbing with solutions of low C_A has possible application in the double-alkali process. In the double-alkali process based on sodium as the absorbent, the concentration of sodium in the absorber loop is limited to about 0.17 mol per 100 mols of water because of solubility limitations in the regeneration section. Ammoniacal solutions, which are not limited to low concentrations in the regeneration loop, would offer economic advantages because the size of the regeneration equipment could be reduced. When using an ammoniacal solution with a C_A of 0.5, the regeneration equipment size could be reduced to about one-third that required with sodium solutions.

A test series was made to determine whether a plume would be present under absorber conditions expected in the double-alkali process. The test series was made using the flow configuration shown in Figure 9. Water was used on the bottom stage (G-1) for humidification liquor with a C_A of 10 and an S/C_A of 0.8 are presented in Table 3. The ammonia required to react with the SO_2 was added to the second-stage absorber loop (F-2 tank). Approximately 90% of the SO_2 was removed under these conditions. Approximately 13% of the absorbed SO_2 was oxidized to ammonium sulfate.

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TABLE 3

TYPICAL ABSORBER LOOP TEST

AMMONIA ABSORPTION AMMONIUM BISULFATE PILOT PLANT

Test conditions	NH_3 to F-2 tank (normal operation)
Gas to scrubber	
Flow rate, scfm at 32°F	2650
Temperature, °F	285
SO_2, ppm	2360
Gas leaving first stage	
Temperature, °F	127
SO_2, ppm	1440
Gas leaving second stage	
Temperature, °F	125
SO_2, ppm	360
Gas leaving scrubber	
Temperature, °F	122
Wet bulb	115
Dry bulb	117
SO_2, ppm	280
SO_2 removal, %	88
Forward feed flow rate,[b] gpm	1.3
Liquor to top stage	
C_A	1.4
S/C_A	0.78
pH	6.1
Specific gravity	1.036
Liquor to middle stage	
C_A	5.1
S/C_A	0.62
pH	6.8
Specific gravity	1.098
Liquor to bottom stage	
C_A	10.8
S/C_A	0.81
pH	5.7
Specific gravity	1.200
Product from scrubber	
C_A	10.4
S/C_A	0.84
pH	5.7
Specific gravity	1.202
Flow rate, gpm	0.41

---

[a] The only forward feed added to the system was water and gaseous ammonia.

TABLE 4

TYPICAL REGENERATION LOOP OPERATION

AMMONIA-ABSORPTION AMMONIUM BISULFATE PILOT PLANT

Test conditions	Acidulation with H_2SO_4 only
Acidulator	
Liquor feed in	
C_A	9.8
S/C_A	0.83
pH	6.0
Specific gravity	1.193
Flow rate, gpm	0.36
Sulfuric acid	
Flow rate, gpm	0.11
Percent sulfuric acid	93
Stoichiometry[a]	1.2
Liquor flow out	
C_A	1.3
S/C_A	1.0
pH	2.0
Specific gravity	1.194
Percent SO_2 release	85
Stripper	
Stripping gas	
Type gas	Air
Flow rate, cfm at 70°F	12
Liquor flow out	
C_A	0.2
S/C_A	1.0
pH	2.1
Specific gravity	1.188
Percent SO_2 release	83
Overall % SO_2 release	97

[a] Stoichiometry is the ratio of mols of acid ion to mols NH_3 as ammonium bisulfite and ammonium sulfite in the liquor to the acidulator.

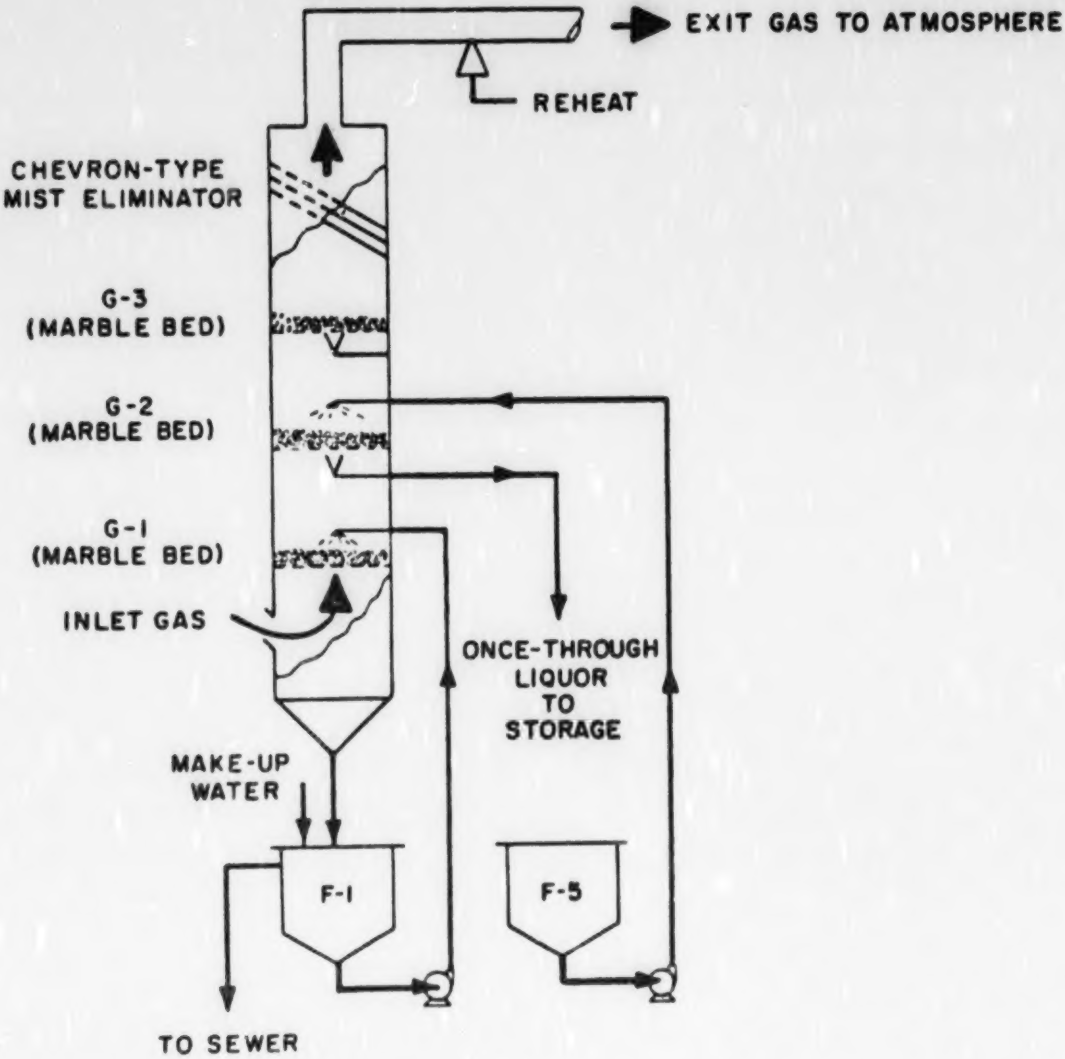

FIGURE 9

FLOW CONFIGURATION FOR DOUBLE-ALKALI TESTS USING AMMONIACAL SOLUTIONS and fly ash removal. Forward feed liquor (ammoniacal solution) was pumped to the middle stage (G-2) at 30 gpm on a once-through basis and then drained to the product liquor hold tank. The gas leaving the absorber was reheated during most of the test series by direct heating with a propane torch.

A steam plume as well as a minor residual particulate plume was present when scrubbing flue gas with water only (Fig. 10). The steam component of the plume was dissipated when the exit gas was reheated to 175°F, but a light particulate plume remained (Fig. 11). An additional plume component was present when an ammoniacal solution was used. The opacity of the plumes produced when scrubbing with solutions having C_A's of 0.5 or 1.0 was reduced to 10% or less by reheating to 175°F. The severe plume while scrubbing with a solution having a C of 1.0 and with no gas reheat is shown in Figure 12. The reduced plume from this operation while reheating to 175°F is shown in Figure 13. The SO_2 removal efficiencies varied from 75 to 85% during these tests.

In one test, two-stage absorption was used to increase SO_2 removal. The forward feed liquor was pumped to the middle and top stages at a rate of 30 gpm to each. An average SO_2 removal of 92% resulted when operation with solutions having a C_A of 1.8 to both absorbing stages. Reheating to 200°F was required in this test sequence to lower the plume opacity to 20% or less (Fig. 14).

It was concluded from these tests that the opacity of the plume produced during operation with these solutions having low ammonia contents can be made acceptable by reheating the exit gas to a temperature necessary to dissipate the steam component of the plume. This temperature will vary according to the temperature and relative humidity of the ambient air.

Modified Pilot-Plant Operation

The absorption section of the pilot plant was operated from April 16 to May 4, 1973, to study additional methods of making the plume acceptable (5% or less opacity judged by qualified visual emissions observers). This operation was carried out in cooperation with Air Products and Chemicals, Inc., Allentown, Pennsylvania.

The tests were made to determine whether the plume leaving the absorber could be made acceptable by operating with one or more of the following:

- Insulated absorber
- A water wash ahead of the first absorber stage

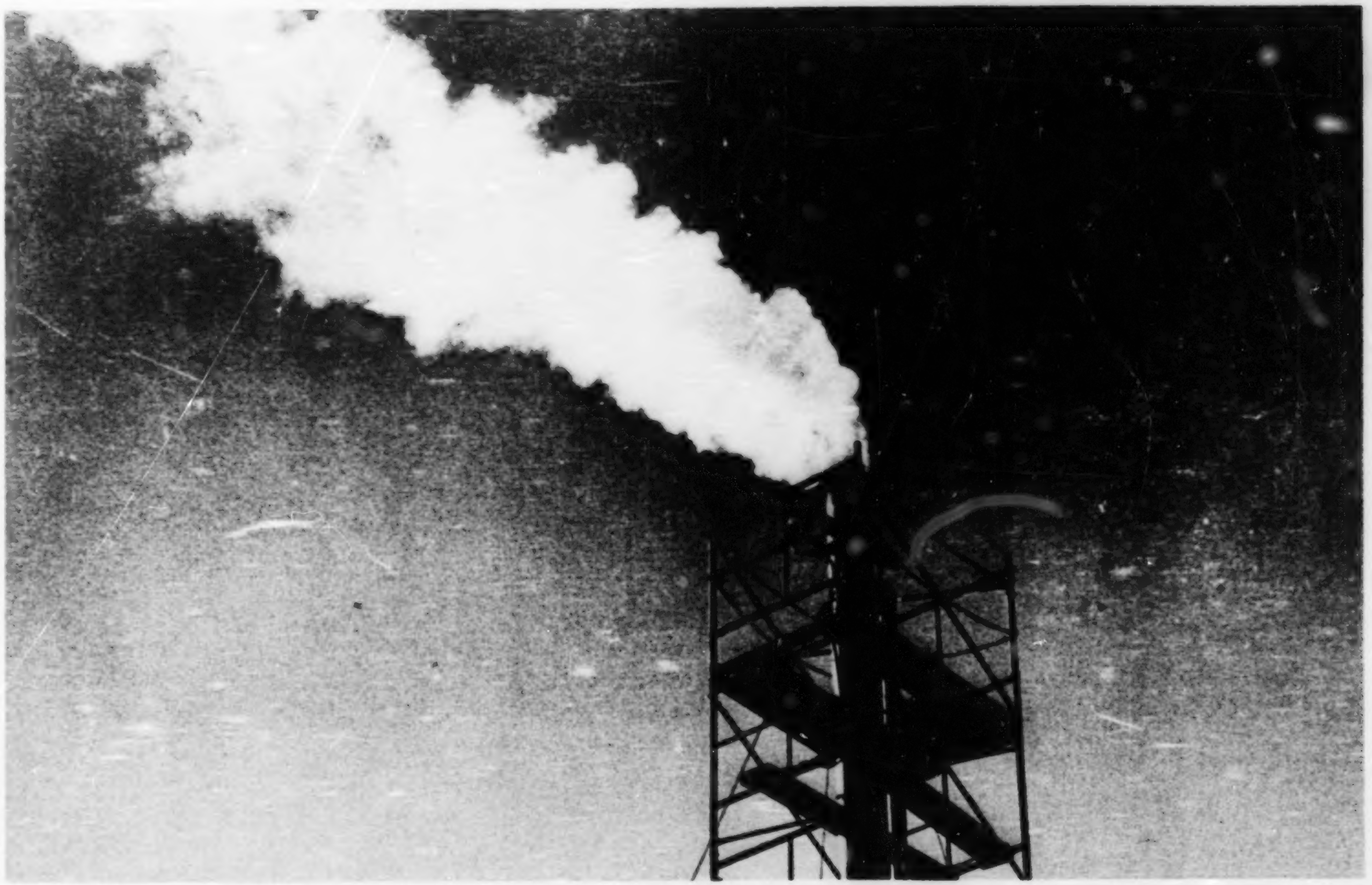

FIGURE 10

Single-Stage Operation, Flue Gas Washed with Water, No Reheat, Ambient Temperature = 57°F, Relative Humidity = 42%

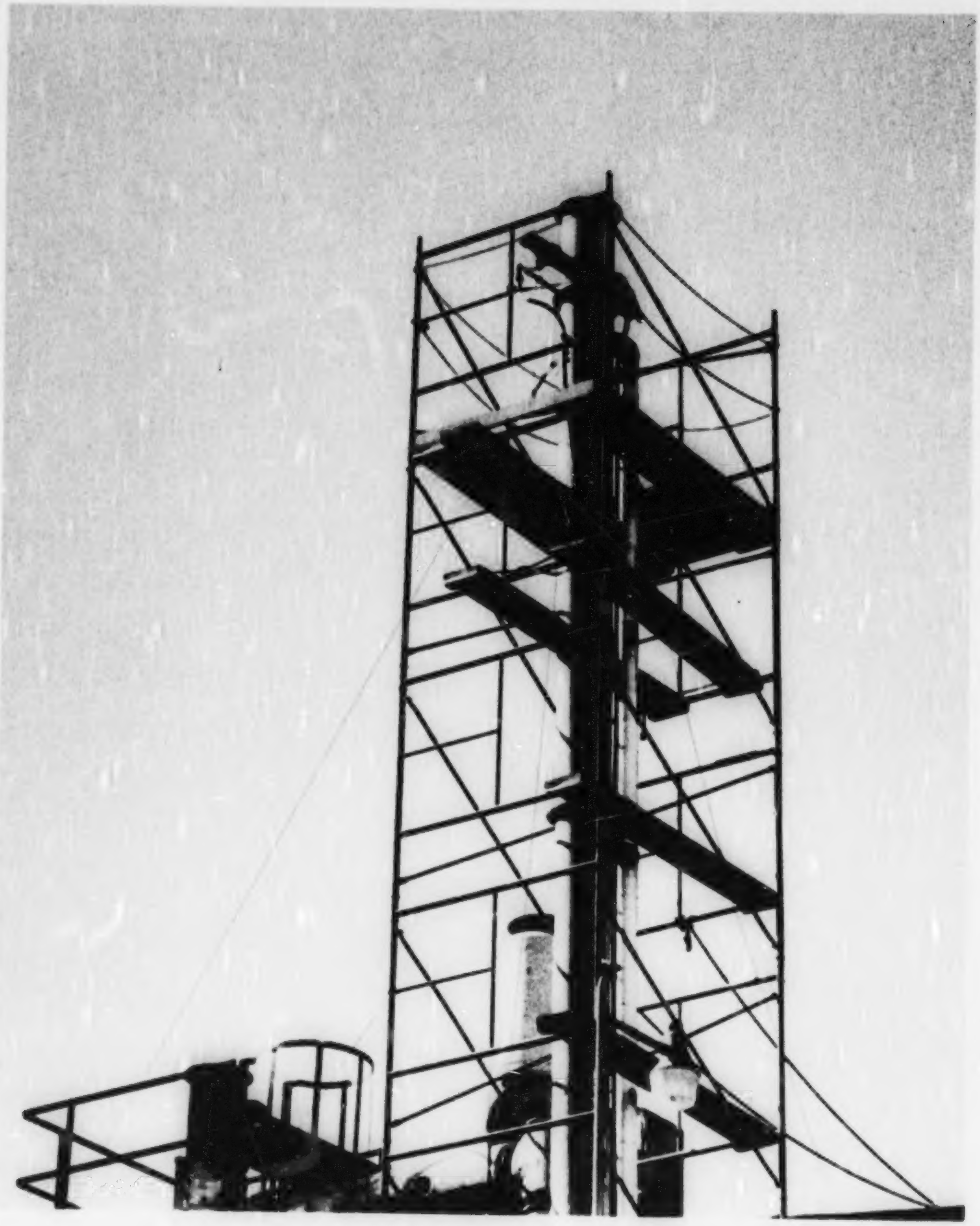

FIGURE 11

Single-Stage Operation, Flue Gas Washed with Water,

Reheat Temperature = 175°F, Ambient Temperature = 57°F,

Relative Humidity = 42%

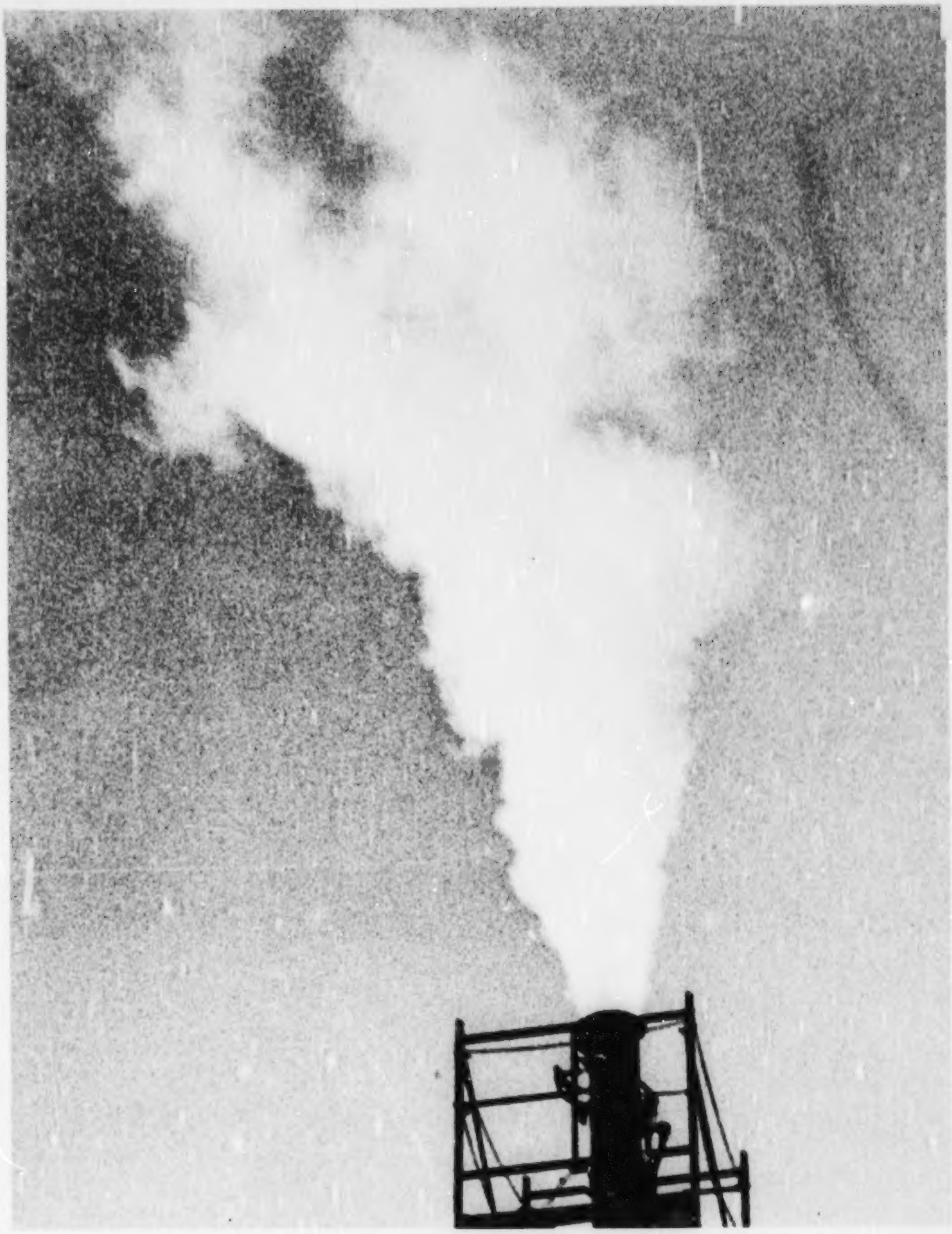

FIGURE 12

Once-Through, Single-Stage Absorber Operation

(Forward Feed to Absorber: $C_A = 1$, $S/C_A = 0.8$)

No Reheat, Ambient Temperature = 49°F, Relative Humidity = 60%

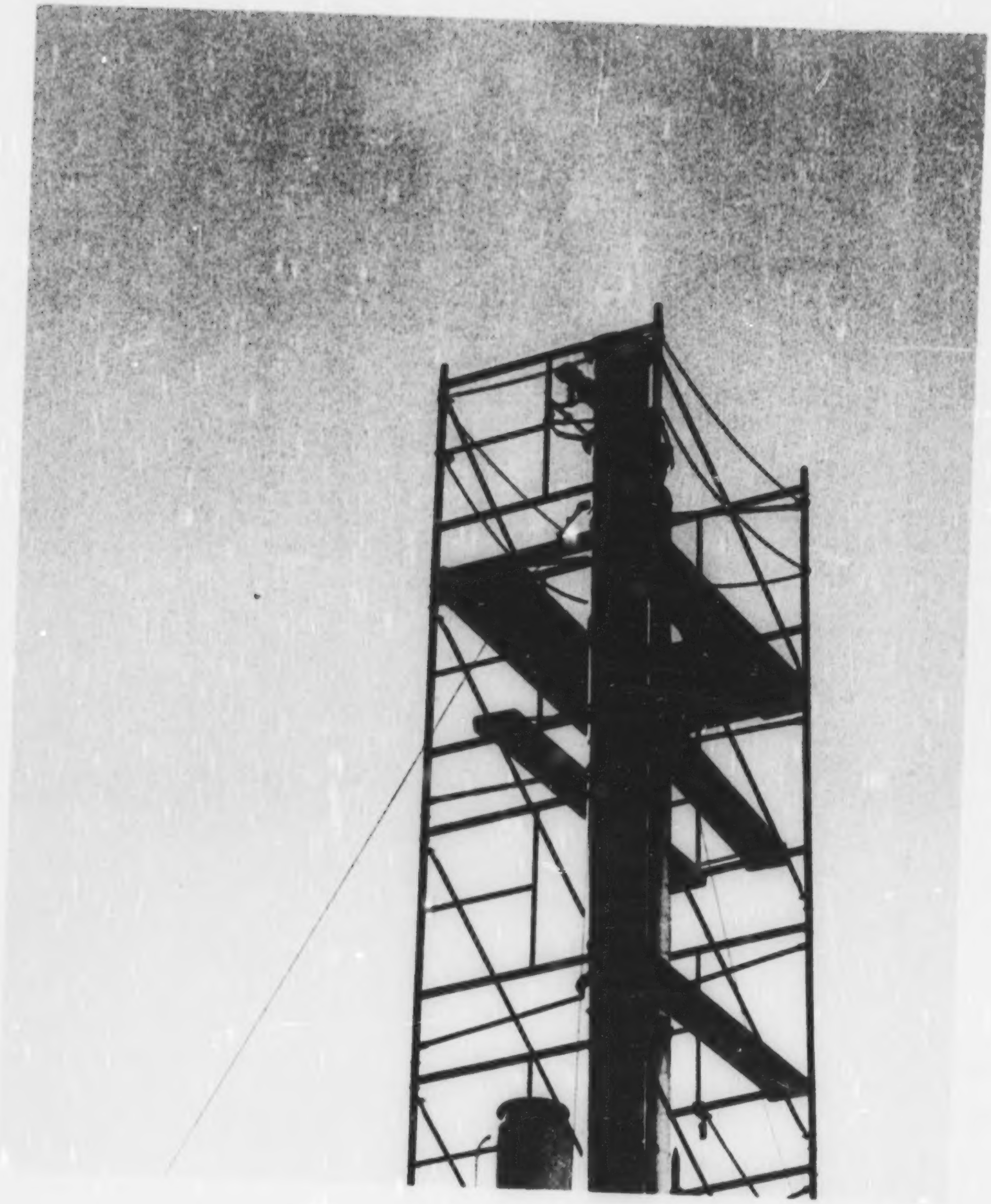

FIGURE 13

Once-Through, Single-Stage Absorber Operation

(Forward Feed to Absorber: $C_A = 1$, $S/C_A = 0.82$)

Reheat Temperature = 175°F, Ambient Temperature = 49°F

Relative Humidity = 60%

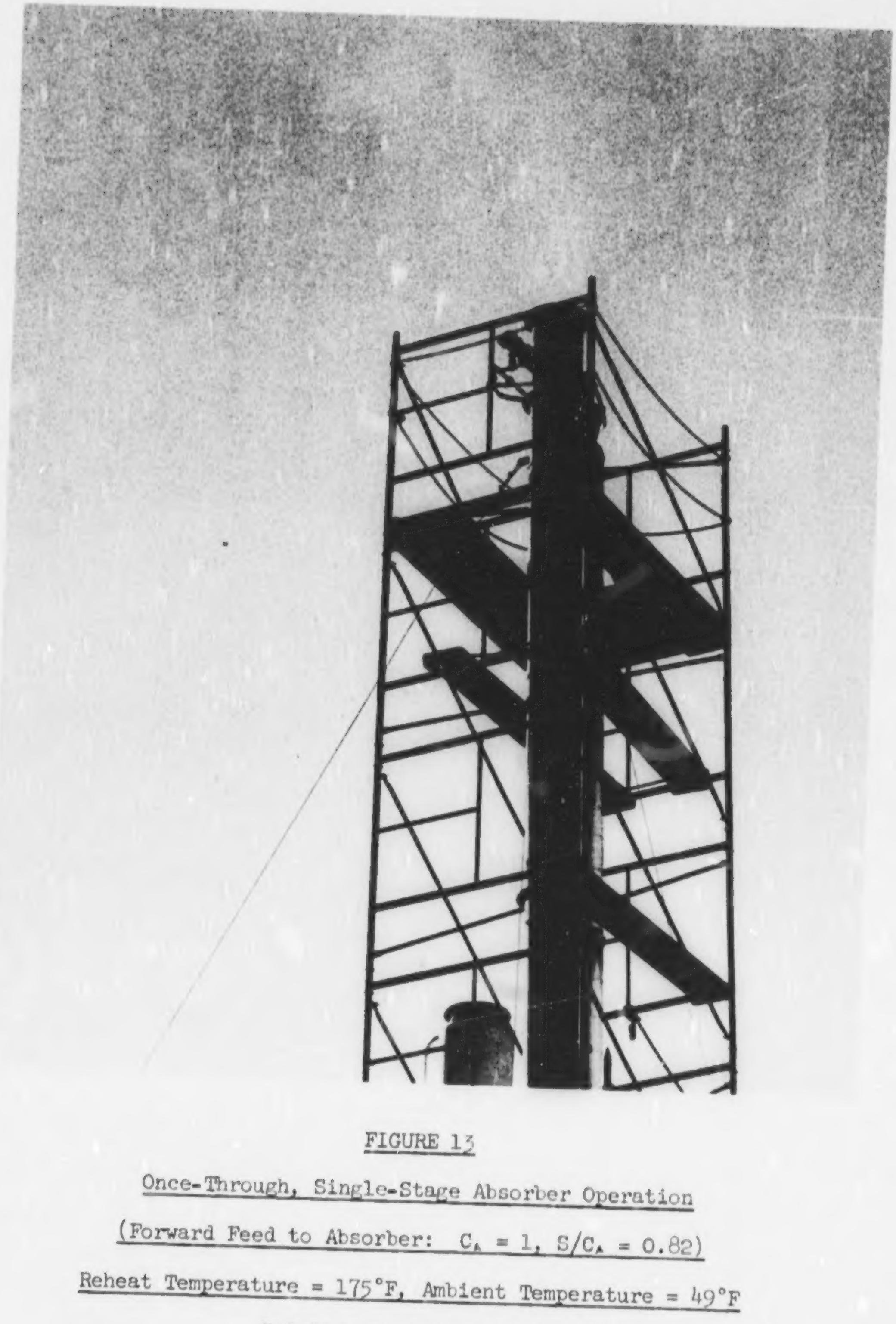

FIGURE 13

Once-Through, Single-Stage Absorber Operation

(Forward Feed to Absorber: $C_A = 1$, $S/C_A = 0.82$)

Reheat Temperature = 175°F, Ambient Temperature = 49°F

Relative Humidity = 60%

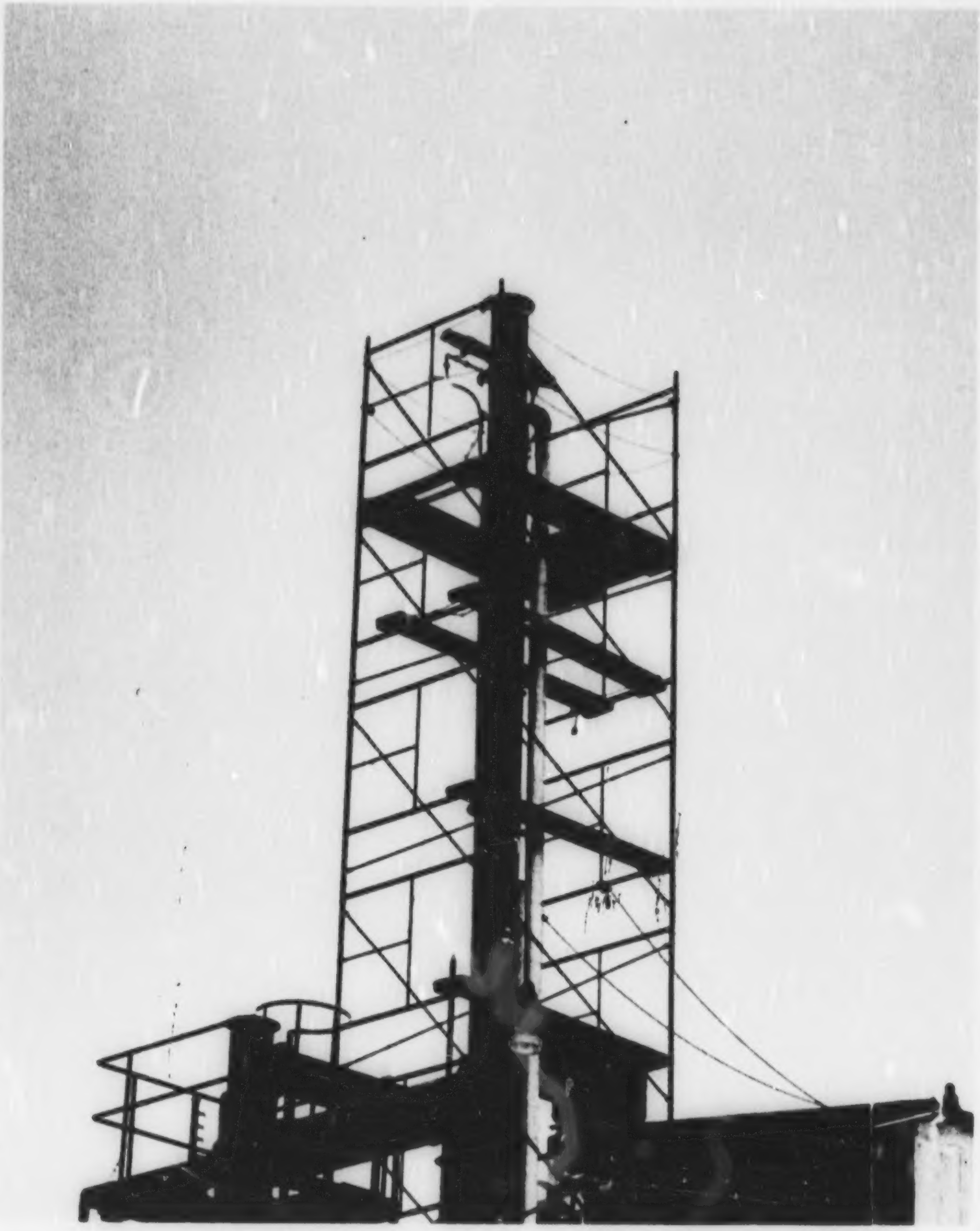

FIGURE 14

Once-Through, Two-Stage Absorber Operation

(Forward Feed to Absorber: $C_A = 1.8$, $S/C_A = 0.70$)

Reheat Temperature = 200°F, Ambient Temperature = 57°F,

Relative Humidity = 42%

- A water wash after the absorber stage

- Reheating the exit flue gas

Two basic flow configurations were used: a recirculation system using one, two, or three stages of absorption (Fig. 15); and a once-through system using one stage of absorption (Fig. 16). The absorber and all downstream ductwork were insulated for reasons that Air Products and Chemicals, Inc., consider proprietary. The water wash ahead of the first absorption stage was used to humidify and cool the hot flue gas, to remove chlorides and thereby prevent formation of an ammonium chloride plume, and to remove fly ash. Humidifying and cooling the flue gas should reduce or eliminate the ammonia-sulfur plume by preventing evaporation of droplets of absorber solution. Evaporation of these droplets could cause localized concentrations of sulfur dioxide and ammonia sufficient for plume formation. The moving marble bed of the bottom stage (G-1) used in previous work was replaced with a multiventuri FlexiTray manufactured by Koch Engineering Company, Inc. No downtime was required when this type of tray was deactivated during absorber operation. (The glass marbles had to be removed from the marble-bed absorber when the unit was deactivated to prevent damage from thermal shock should absorber liquor accidentally come in contact with the hot bed.)

The purpose of the water wash after the absorption stage was to decrease the salt content of the entrained mist leaving the absorber. Reheating would have evaporated the mist and produced an increased concentration of ammonia and sulfur dioxide in the exit flue gas which could have then reacted to form a plume. The top stage of the absorber (G-3) was used for this wash. The gas leaving the absorber was directly reheated with a propane torch to destroy the ammonia-based particulate matter present and eliminate a steam plume. The retention time of the heated flue gas in the ductwork was 1.5 seconds.

A summary of the test conditions and the opacity readings for each test are given in Table 5. These tests indicate that a plume with acceptable opacity was obtained during production of liquor with high C_A's when:

- Water wash stage was used ahead of the first absorber

- Absorber and all ducts were insulated

- Reheat was applied as required to dissipate the steam plume

Comparison of Figure 17 and Figure 18 shows the effect of the water wash ahead of the first absorber stage. In Figure 17, the water wash was not employed and the opacity was 5%. The water wash was activated and the opacity dropped to 0% (Fig. 18).

The concentration of ammonia salts in the range C_A of 0.1 to 3 in the water wash (G-3) after the absorption stage did not significantly affect the plume opacity.

The chloride concentration of the inlet flue gas was approximately 30 ppm and in the exit gas was about 3 ppm.

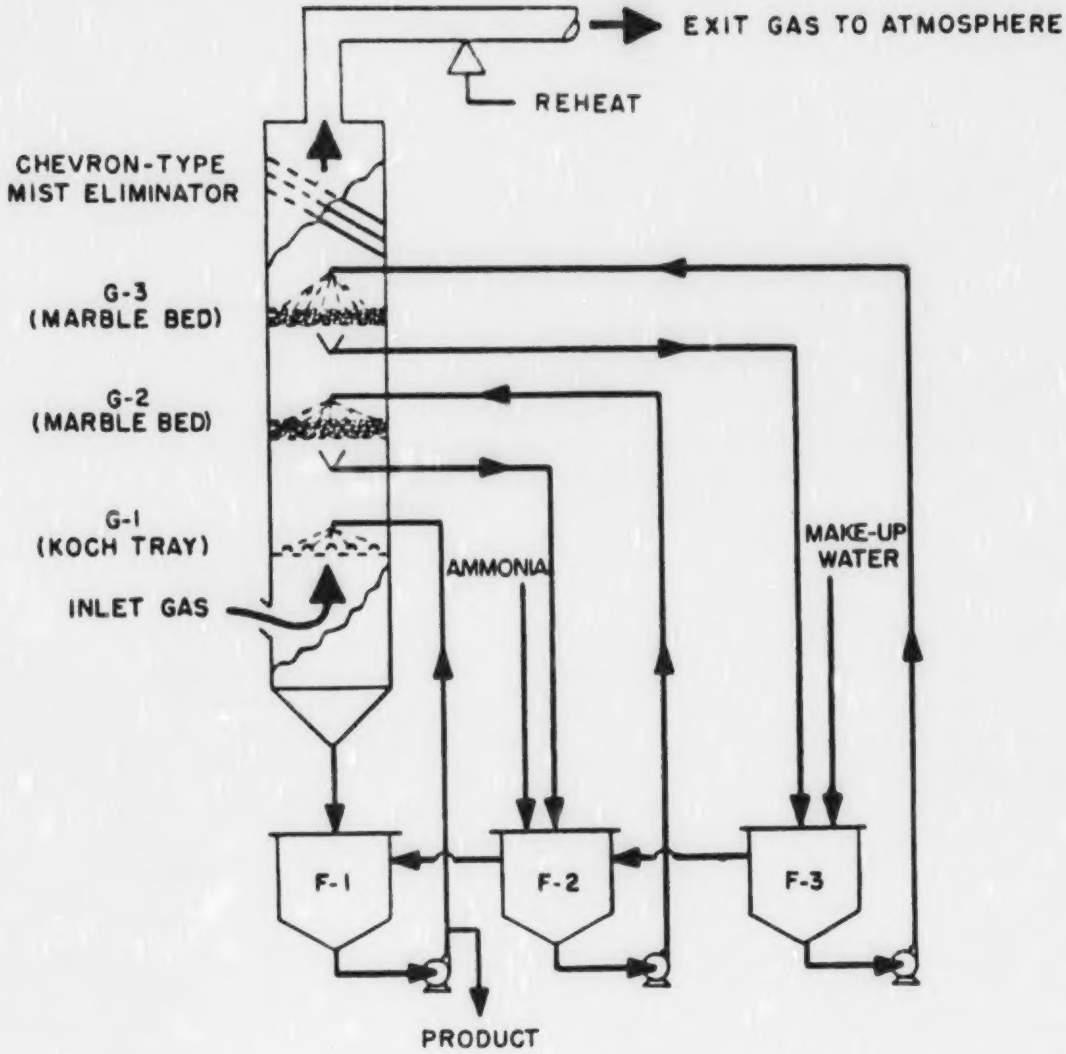

FIGURE 15

RECIRCULATING FLOW CONFIGURATION

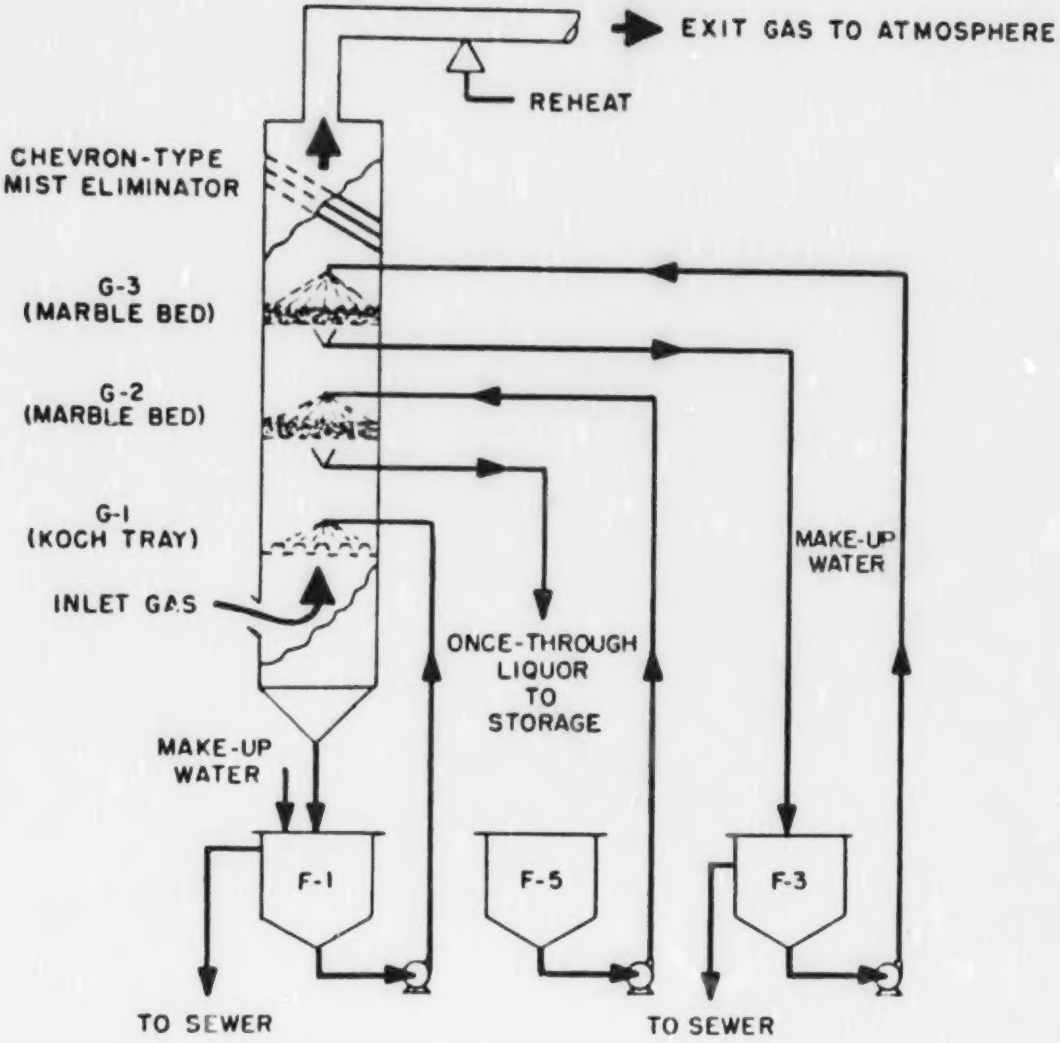

FIGURE 16

ONCE-THROUGH FLOW CONFIGURATION

TABLE 5

SUMMARY OF OPERATING DATA FOR THE PILOT PLANT
FOR AMMONIA ABSORPTION - AMMONIUM BISULFATE REGENERATION PROCESS
(INSULATED TEST SERIES, APRIL - MAY 1973)

Test No.	0	I-1	I-2A	I-2B	I-2C	I-2D	I-3	I-4
Date	4/19	4/20	4/20	4/20	4/20	4/20	4/20	4/20
Time	11:00 a.m.	1:00 p.m.	1:45 p.m.	2:15 p.m.	3:15 p.m.	3:40 p.m.	5:55 p.m.	6:05 p.m.
Liquor flow configuration	← Recirculating →							
Flow								
Liquor, gpm								
To G-1 (bottom stage)	30	30	33	31	31	30	29	30
To G-2 (middle stage)	30	30	30	30	30	30	30	30
To G-3 (top stage)	15	15	15	15	15	15	15	15
Gas, cfm	2700	2700	2700	2700	2700	2700	2700	2700
Liquor C_A[a]								
G-1-I[b]	28.1	13.21	12.6	14.0	-	13.0	0.85	0.85
G-1-O[c]	-	13.09	13.0	13.8	-	13.6	1.50	1.50
G-2-I[b]	9.52	4.90	5.2	4.9	-	4.5	10.6	10.6
G-2-O[c]	9.48	4.73	5.2	5.0	-	4.5	10.4	10.4
G-3-I[b]	1.35	-	0.1	0.1	-	1.2	0.14	0.14
G-3-O[c]	1.88	0.10	0.6	0.4	-	1.4	0.31	0.31
Liquor S/C_A[d]								
G-1-I	0.76	0.82	0.85	0.81	-	0.79	0.95	0.95
G-1-O[c]	-	0.83	0.84	0.82	-	0.79	0.93	0.93
G-2-I[b]	0.58	0.55	0.55	0.56	-	0.60	0.78	0.78
G-2-O[c]	0.59	0.57	0.57	0.57	-	0.62	0.79	0.79
G-3-I[b]	0.62	-	0.84	0.85	-	0.72	0.99	0.99
G-3-O[c]	0.60	0.86	0.58	0.61	-	0.70	0.95	0.95
Liquor pH								
G-1-I[b]	5.90	5.75	5.80	5.80	5.80	5.80	5.10	5.10
G-1-O[c]	-	5.75	5.75	5.75	5.90	5.90	5.70	5.70
G-2-I[b]	6.70	7.25	7.10	7.10	6.80	6.80	5.90	5.90
G-2-O[c]	6.70	6.95	6.95	6.95	6.70	6.70	5.90	5.90
G-3-I[b]	6.70	7.20	7.25	7.25	6.50	6.50	5.70	5.70
G-3-O[c]	6.80	7.10	7.15	7.15	6.50	6.50	4.90	4.90
SO_2, ppm								
Entering G-1	2600	2320	2440	2600	2400	2400	2520	2520
Leaving G-1	1700	1860	2000	1880	2040	1640	1760	1760
Leaving G-2	80	400	300	160	160	240	920	920
Leaving G-3	40	100	40	60	60	160	920	920
Percent removal	98.5	95.6	98.4	97.7	97.5	93.3	63.5	63.5
NH_3 leaving G-3, ppm	47	47	51	51	51	50	87	-
Temperatures, °F								
Liquor								
From G-1	141	131	131	130	131	131	121	121
From G-2	126	127	127	127	126	128	129	129
From G-3	125	126	126	126	125	125	122	122
Gas								
To G-1	282	290	289	286	290	290	270	270
From G-1	144	132	133	132	133	133	124	124
From G-2	130	127	127	126	127	127	129	129
From G-3	126	125	125	125	125	126	121	121
Exit gas	200	150	200	220	225	200	160	-
Ambient	73	84	85	85	82	84	83	83
Relative humidity, %	60	49	47	47	42	42	42	42
Predicted minimum temperature at which steam plume forms, °F[e]	152	120	120	120	124	120	124	124
Reheat temperature, °F	200	150	200	220	225	200	160	None
Percent opacity	25	65	15	20	10	15	Nil	5

TABLE 5 (CONT.)

Test No.	I-5	I-6A	I-7	I-8A	I-13	I-14A	I-15	I-16A
Date	4/23	4/23	4/23	4/23	4/24	4/24	4/24	4/24
Time	2:15 p.m.	1:45 p.m.	2:40 p.m.	3:05 p.m.	3:15 p.m.	3:45 p.m.	4:30 p.m.	4:10 p.m.
Liquor flow configuration	← Once through →							
Flow								
Liquor, gpm								
To G-1 (bottom stage)	31	32	0	0	30	30	0	0
To G-2 (middle stage)	31	32	30	30	30	30	30	30
To G-3 (top stage)	15	15	17	17	15	15	15	15
Gas, cfm	2700	2700	2700	2700	2700	2700	2700	2700
Liquor C_A^{a}								
G-1-I^b	0.30	0.30	-	-	0.12	0.12	-	-
G-1-O^c	0.50	0.50	-	-	0.11	0.11	-	-
G-2-I^b	10.1	10.1	9.1	9.1	1.9	1.9	1.8	1.8
G-2-O^c	10.1	10.1	8.9	8.9	1.9	1.9	1.7	1.7
G-3-I^b	0.21	0.21	0.30	0.30	0.33	0.33	0.23	0.23
G-3-O^c	0.38	0.38	0.41	0.41	0.29	0.29	0.24	0.24
Liquor S/C_A^{d}								
G-1-I^b	0.93	0.93	-	-	0.50	0.50	-	-
G-1-O^c	0.88	0.88	-	-	0.70	0.70	-	-
G-2-I^b	0.77	0.77	0.77	0.77	0.76	0.76	0.78	0.78
G-2-O^c	0.78	0.78	0.79	0.79	0.81	0.81	0.86	0.86
G-3-I^b	0.72	0.72	0.93	0.93	0.78	0.78	0.95	0.95
G-3-O^c	0.81	0.81	0.90	0.90	0.91	0.91	0.95	0.95
Liquor pH								
G-1-I^b	4.70	4.70	-	-	2.40	2.40	-	-
G-1-O^c	5.90	5.90	-	-	2.30	2.30	-	-
G-2-I^b	6.00	6.00	5.80	5.80	6.00	6.00	6.00	6.00
G-2-O^c	6.00	6.00	5.80	5.80	5.80	5.80	5.70	5.70
G-3-I^b	4.70	4.70	5.10	5.10	3.10	3.10	3.10	3.10
G-3-O^c	5.00	5.00	4.20	4.20	3.10	3.10	2.90	2.90
SO_2, ppm								
Entering G-1	2560	2480	2480	2480	2480	2600	2600	2600
Leaving G-1	2600	2520	2480	2480	2520	2600	2540	2540
Leaving G-2	880	880	920	920	480	440	440	580
Leaving G-3	680	720	780	780	560	560	600	64
Percent removal	73.4	70.9	68.5	68.5	77.4	78.5	76.9	75.4
NH_3 leaving G-3, ppm	47	47	79	-	37	39	34	34
Temperatures, °F								
Liquor								
From G-1	125	127	-	-	125	125	-	-
From G-2	130	130	128	128	126	126	128	126
From G-3	130	127	124	124	125	125	126	125
Gas								
To G-1	290	290	290	288	288	286	286	284
From G-1	127	128	274	285	125	126	268	255
From G-2	130	130	138	128	126	127	127	127
From G-3	125	125	124	124	125	126	125	124
Exit gas	150	200	150	200	150	200	150	200
Ambient	72	70	72	72	65	66	66	66
Relative humidity, %	84	84	80	80	93	93	92	92
Predicted minimum temperature at which steam plume forms, °F^e	159	160	154	154	181	181	181	181
Reheat temperature, °F	150	200	150	200	150	200	150	200
Percent opacity	20	5	30	5	90/15 at lip	0	80/30 at lip	5

TABLE 5 (CONT.)

Test No. Date Time Liquor flow configuration	I-17 4/26 3:05 p.m.	I-17 4/27 1:45 p.m.	I-18 5/1 1:00 p.m.	I-18 5/2 4:00 p.m.
	← Recirculating			→
Flow				
Liquor, gpm				
To G-1 (bottom stage)	30	31	30	30
To G-2 (middle stage)	30	30	30	30
To G-3 (top stage)	25	26	25	25
Gas, cfm	3000	3000	2900	2700
Liquor C_A[a]				
G-1-I[b]	0.03	0.03	-	0.04
G-1-O[c]	0.03	0.03	-	0.04
G-2-I[b]	11.6	11.6	11.62	7.61
G-2-O[c]	11.8	11.8	11.72	8.39
G-3-I[b]	0.29	0.29	2.06	2.94
G-3-O[c]	0.38	0.38	2.39	3.21
Liquor S/C_A[d]				
G-1-I[b]	-	-	-	-
G-1-O[c]	-	-	-	-
G-2-I[b]	0.74	0.74	0.75	0.82
G-2-O[c]	0.75	0.75	0.75	0.79
G-3-I[b]	0.93	0.93	0.93	0.95
G-3-O[c]	0.93	0.93	0.89	0.92
Liquor pH				
G-1-I[b]	2.30	2.30	2.20	2.40
G-1-O[c]	2.20	2.20	2.20	2.30
G-2-I[b]	6.00	6.00	6.00	5.80
G-2-O[c]	5.90	5.90	5.90	5.70
G-3-I[b]	5.30	5.30	5.60	5.40
G-3-O[c]	5.50	5.50	5.60	5.40
SO_2, ppm				
Entering G-1	2620	2840	2640	2520
Leaving G-1	2440	2560	2480	2400
Leaving G-2	600	680	560	560
Leaving G-3	680	400	440	800
Percent removal	74.0	85.9	83.3	68.3
NH_3 leaving G-3, ppm	89	70	93	85
Temperatures, °F				
Liquor				
From G-1	124	120	125	110
From G-2	128	128	134	125
From G-3	124	121	129	122
Gas				
To G-1	280	272	295	294
From G-1	124	120	125	115
From G-2	128	128	133	124
From G-3	124	120	127	121
Exit gas	200	160	200	160
Ambient	60	57	74	80
Relative humidity, %	96	51	64	56
Predicted minimum temperature at which steam plume forms, °F[e]	198	170	141	131
Reheat temperature, °F	200	160	200	160
Percent opacity	40/5 at lip	15/10 at lip	10/5 at lip	5

---

[a] Mols of active ammonia as ammonium sulfite-bisulfite per 100 mols of water.

[b] Inlet sample.

[c] Outlet sample.

[d] Mol ratio of SO_2:NH_3.

[e] Calculated minimum temperature at which steam plume can form regardless of dilution; does not include a solid particulate plume, that is, an ammonia salt plume.

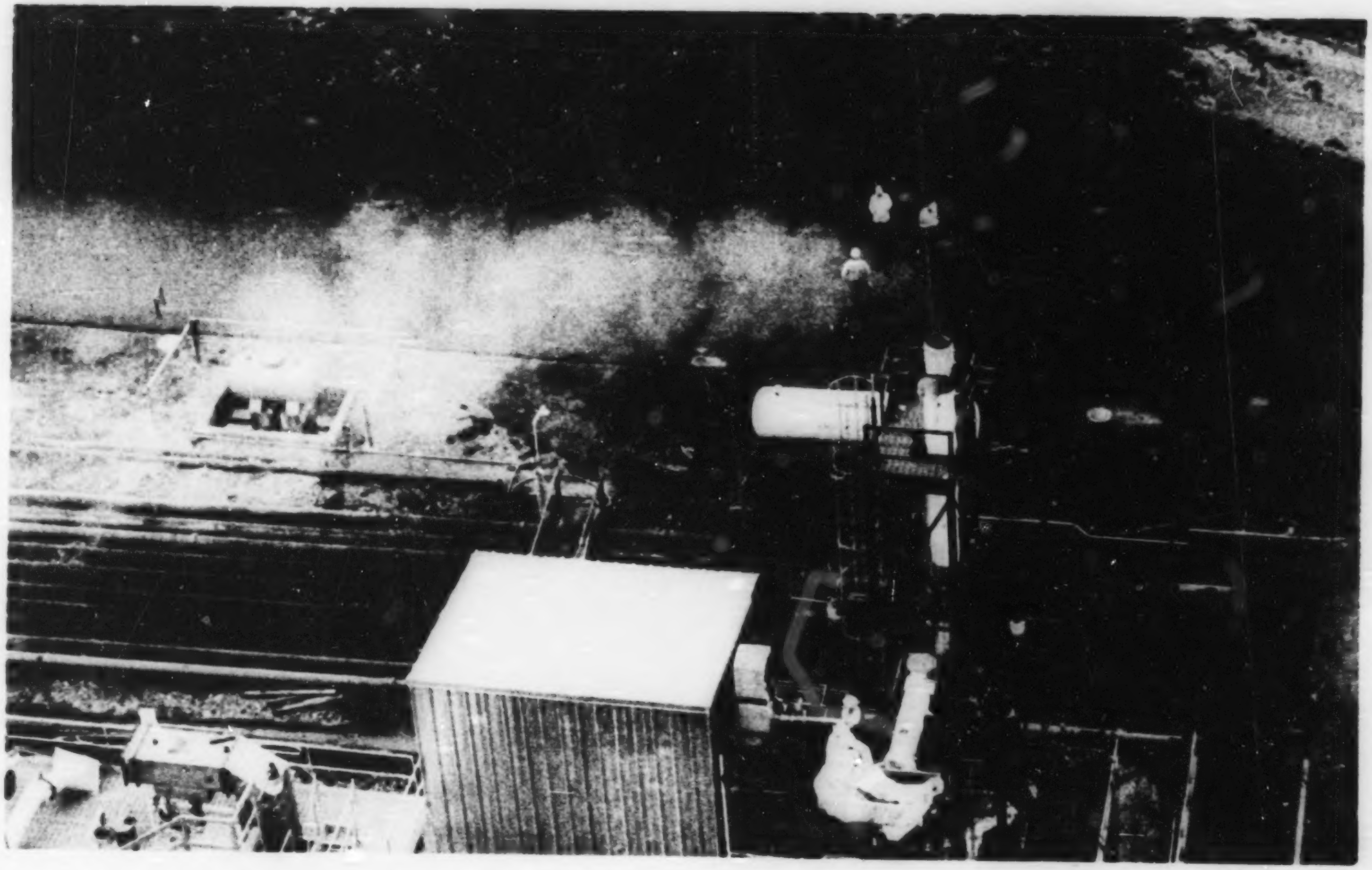

FIGURE 17

Once-Through, Single-Stage Absorber Operation (Forward Feed to Absorber: $C_A = 2$, $S/C_A = 0.8$)

Reheat Temperature = 200°F, Ambient Temperature = 92°F

Relative Humidity = 66%, No Wash Water Before Absorption Stage

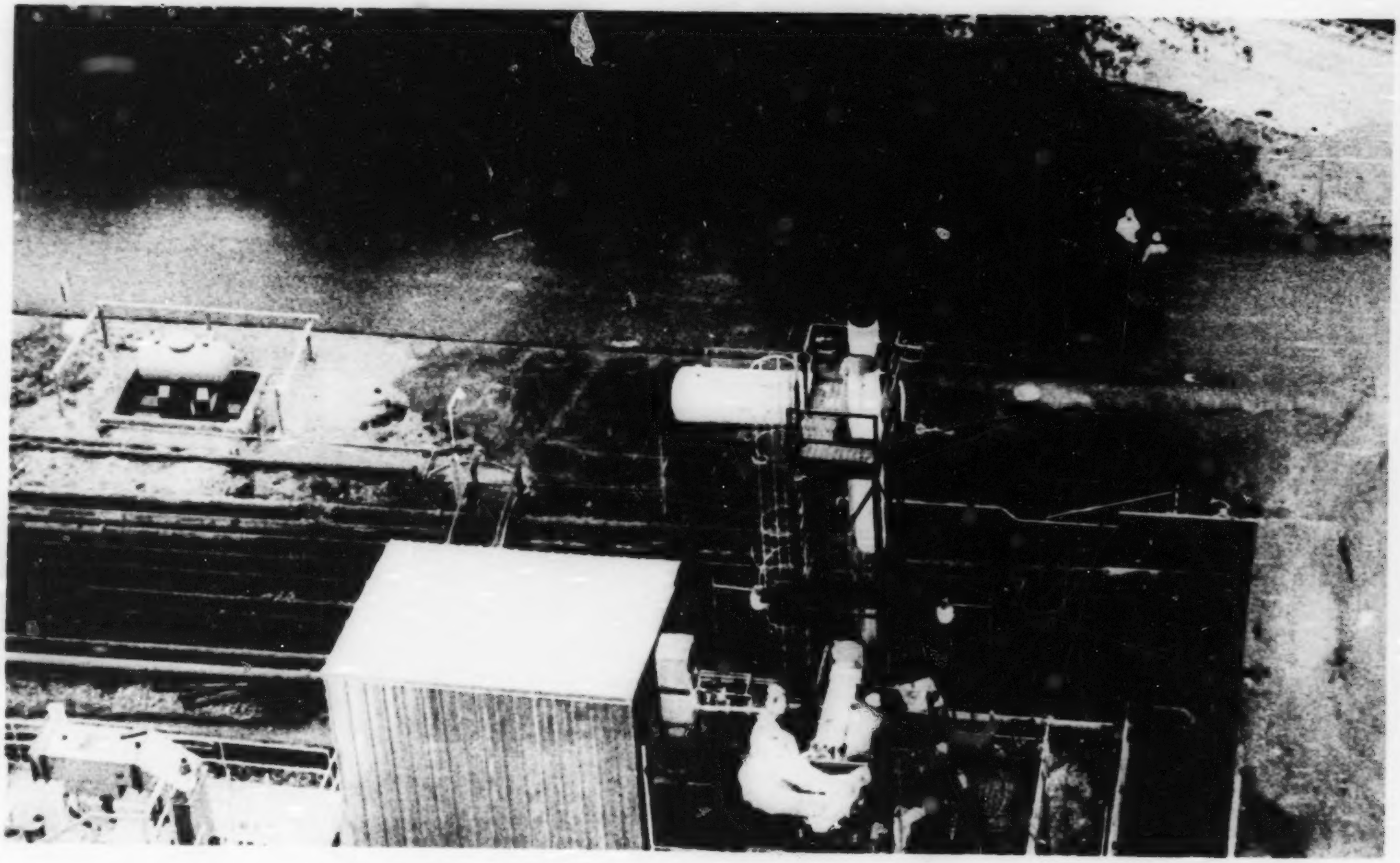

FIGURE 18

Once-Through, Single-Stage Absorber Operation (Forward Feed to Absorber: $C_A = 2$, $S/C_A = 0.8$)

Reheat Temperature = 200°F, Ambient Temperature = 93°F

Relative Humidity = 66%, Wash Water Before Absorption Stage

The effect of chloride removal on plume reduction could not be separated from the effects of cooling and humidifying the gas ahead of the first absorber stage.

Heat losses were minimized by insulating the absorber system. The difference between the liquor temperature and the outside absorber skin temperature averaged about 1 Farenheit degree. In operation without insulation, differences as great as 30 Farenheit degrees were measured. The effect of the insulation in preventing plume formation was not determined.

The reheat required to dissipate the steam plume is a function of the ambient temperature and relative humidity. The reheat temperature required to avoid formation of a steam plume can be predicted for a given scrubber exit temperature and pressure of water vapor, according to the procedure given in Appendix J. The predicted reheat temperature for each test is included in Table 5. Reheating the gas to a temperature above the predicted reheat temperature resulted in an acceptable plume when a water wash was used ahead of the absorber. In one test (I-4), an acceptable plume was obtained without reheating (Fig. 19). In this case, the gas leaving the absorber was at a higher temperature than the predicted reheat temperature. In those tests without a water wash, reheating decreased the plume opacity and in two tests (I-8 and I-16) the decreased opacity reached an acceptable level.

Tests I-17 and I-18 were extended runs designed to show the reheat required as a function of the ambient conditions (temperature and relative humidity). The plume opacity was maintained at a constant 5% by adjusting the reheat temperature of the exit flue gas (maximum temperature set at 200°F). Data from these tests show that the reheat requirements for an acceptable plume increase with increased relative humidity. These data as well as the predicted reheat temperature necessary to avoid formation of a steam plume and the opacity reading of the stack are given below.

Relative humidity, %	Ambient temp., °F	Predicted reheat temp. required to eliminate steam plume, °F	Reheat temp., °F	Opacity reading, % At stack exit	Opacity reading, % 10 feet above stack
94	62	189	125 (No reheat)	50	60
94	62	189	200	5	30
80	65	166	193	5	10
69	63	162	196	5	10
62	68	152	197	5	5
53	57	170	180	5	5
42	60	154	175	5	5
32	82	124	158	5	5

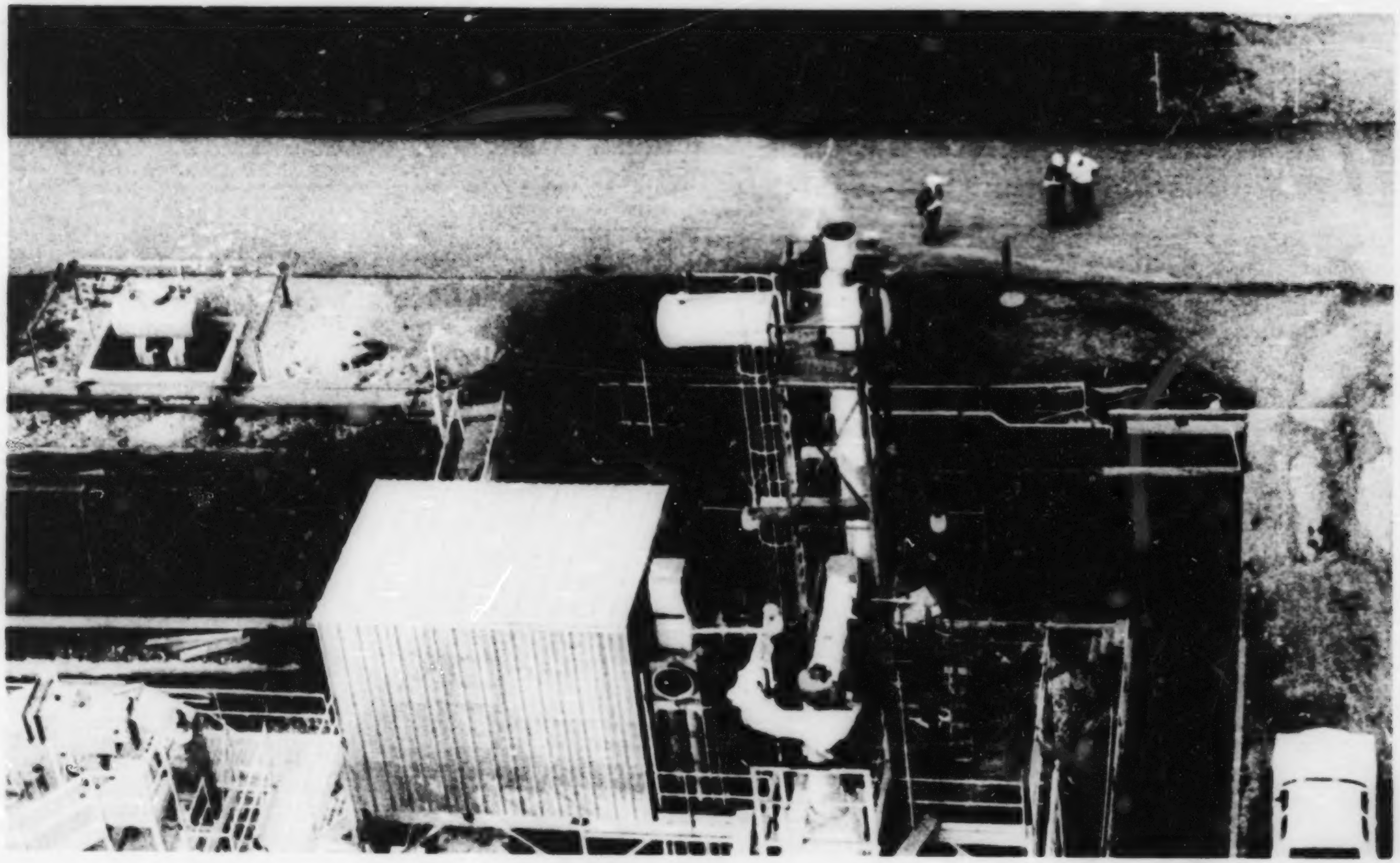

FIGURE 19

Recirculating, Single-Stage Absorber Operation with Acceptable Plume and No Reheat

(Product from Absorber: $C_A = 10$, $S/C_A = 0.8$)

Ambient Temperature = 83°F, Relative Humidity = 42%

Formation of a high-opacity plume several feet from the discharge of the stack occurred on days when the relative humidity was high (see data on page 49). Figure 20 shows a plume reforming downwind from a clear stack. Reheat temperatures required to avoid formation of a plume on days of high relative humidity and low temperature are impractical if not impossible to achieve.

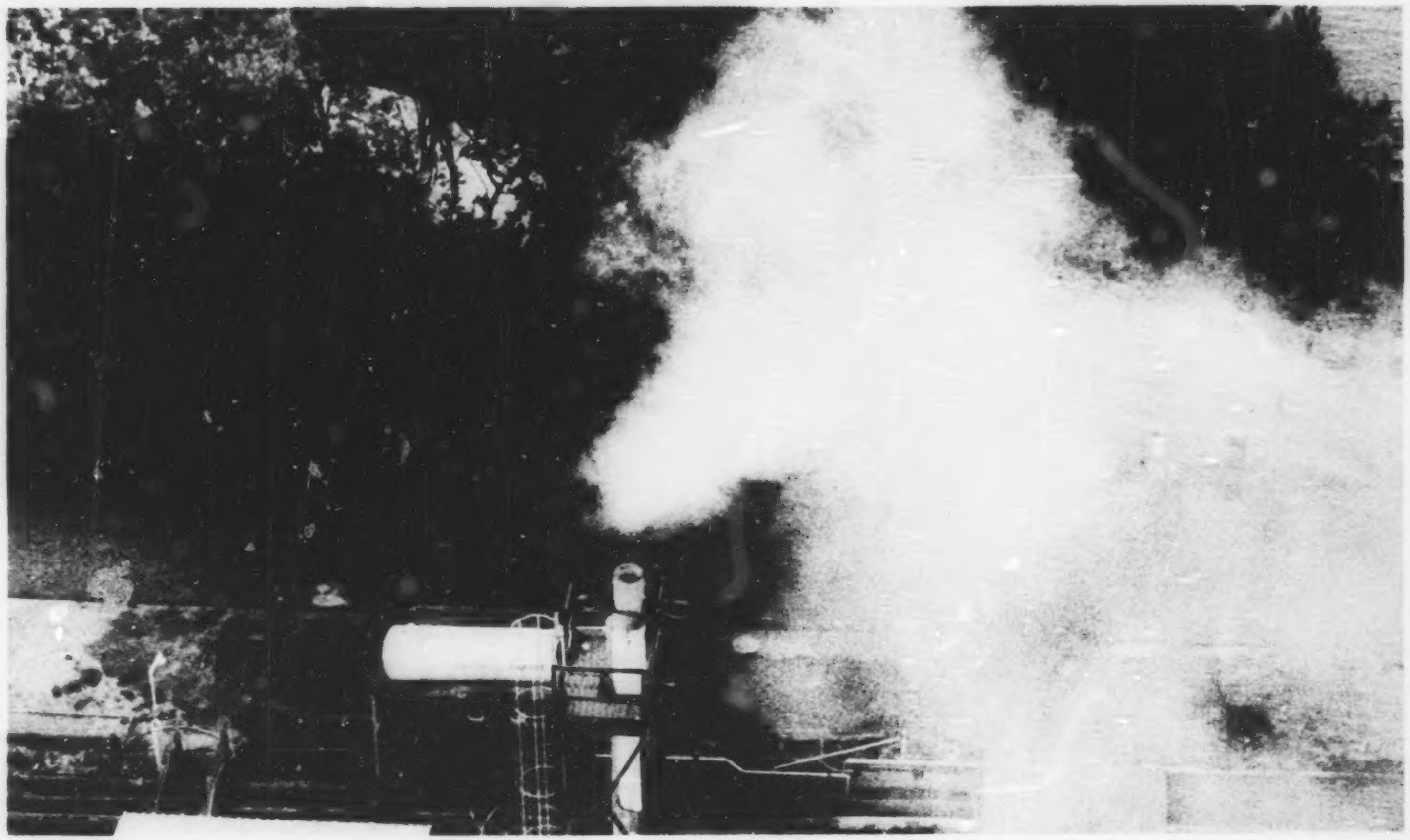

FIGURE 20

Recirculating, Single-Stage Absorber Operation with Plume Reforming Above Stack

(Product from Absorber: $C_A = 12$, $S/C_A = 0.8$)

Reheat Temperature = 200°F, Ambient Temperature = 53°F, Relative Humidity = 94%

REFERENCES

1. Ramsey, "Use of the NH_3–SO_2–H_2O System as a Cyclic Recovery Method," British Patent 1,427 (1883).

2. Lepsoe, R., Kirkpatrick, W. S., "SO_2 Recovery at Trail, A General Picture of the Development and Installation of the Sulfur Dioxide Plant of the Consolidated Mining and Smelting Company of Canada, Limited, at Trail, B.C.," *Trans. Can. Inst. Mining Met.* *40*, (In Can. Mining Met. Bull. No. 304), 399–404 (1937).

3. Johnstone, H. F., "Recovery of SO_2 from Waste Gas: Equilibrium Partial Vapor Pressures Over Solutions of the Ammonia–Sulfur Dioxide–Water System," *Ind. Eng. Chem* *27* (5), 587–93 (May 1935).

4. Johnstone, H. F., Keyes, D. B., "Recovery of SO_2 from Waste Gases: Distillation of a Three–Component System Ammonia–Sulfur Dioxide–Water," *Ind. Eng. Chem.* *27* (6), 659–65 (June 1935).

5. Johnstone, H. F., Singh, A. D., "Recovery of SO_2 from Waste Gases; Design of Scrubbers for Large Quantities of Gases, *Ind. Eng. Chem.* *29* (3), 286–97 (March 1937).

6. Johnstone, H. F., "Recovery of SO_2 from Waste Gases; Effect of Solvent Concentration on Capacity and Steam Requirements of Ammonium Sulfite – Bisulfite Solutions," *Ind. Eng. Chem.* *29* (12), 1396–98 (December 1937).

7. Johnstone, H. F., "Recovery of Sulfur Dioxide from Dilute Gases," *Pulp Paper Mag. Can.* *53* (4), 105–12 (March 1952).

8. Hein, L. B., Phillips, A. B., Young, R. D., "Recovery of SO_2 from Coal Combustion Stack Gases," in *Problems and Control of Air Pollution*, Frederick S. Mallette, ed., New York, Reinhold, 1955, pp 155–69.

9. Slack, A. V., Sulfur Dioxide Removal from Waste Gases, Park Ridge, New Jersey, Noyes Data Corporation, 1971, pp 118–9, (Pollution Control Review No. 4).

10. Nakagawa, S., Japan Engineering Consulting Company, Tokyo, Japan, Private Communication 1968.

11. "SO_2 – Recovery from Sulphuric Acid Plant Off–Gases," *Sulphur*, No. 80, 36–8 (January–February 1969).

12. Romania, Ministry of Petroleum and Chemical Industry, "Ammonium Sulfate, British Patent 1,097,257 (January 3, 1968) 2 pp.

13. Alabama Power Company, "New Process of Fertilizer Manufacture Announced," *Mfr. Rec.* *92* (26), 53 (December 29, 1927).

14. Rubin, Allen G., Bohna Engineering and Research, Inc., San Francisco, California, Private Communication, 1973.

15. Hixson, A. W. and Miller, R., "Sulfur Dioxide from Flue Gases," U. S. Patent 2,405,747, (August 13, 1946).

16. Babcock and Wilcox Company, Steam Its Generation and Use, 37th ed., New York, New York, 1955, pp. 11–24 and Figure 25.

17. King, R. A., "Economic Utilization of Sulfur Dioxide from Metallurgical Gases," *Ind. Eng. Chem* *42* (11), 2241–8 (November 1950).

18. Gottfried, J., Nyvlt, J., Hayerova, Z., "Phase Equilibrium in the System $(NH_4)_2SO_4-(NH_4)_2SO_3-NH_4HSO_3-H_2O$," *Chem Prumysl* *16* (3), 149–54 (1966).

19. Tennessee Valley Authority, "Sulfur Oxide Removal from Power Plant Stack Gas– –Ammonia Scrubbing– –Production of Ammonium Sulfate and Use as an Intermediate in Phosphate Fertilizer Manufacture," Report Y-13. Prepared for National Air Pollution Control Administration, NTIS No. PB 196–804 (1970).

20. Environmental Protection Agency, Standards of Performance for New Stationary Sources. Fed. Reg. December 23, 1971, 36 (247), Part II.

21. Crocker, B. B., "Water Vapor in Effluent Gases: What to do About Opacity Problems," *Chem.Eng.* *75* (15), 109–16 (July 15, 1968).

22. Kalika, P. W., "How Water Recirculation and Steam Plumes Influence Scrubber Design," *Chem. Eng.* *76* (16), 133–8 (July 28, 1969).

APPENDIX A - PROCESS VARIATIONS

Removal of sulfur oxides from stack gas by absorbing them in ammoniacal solutions has many appealing features. These include:

1. Wide availability and relatively low cost ammonia.
2. High solubility of ammonium sulfites in water—particularly at low sulfate concentrations.
3. Ease of regeneration to recover sulfur dioxide, ammonia, and ammonium sulfate.

The ammonia can be recycled to the absorber and the sulfur dioxide can be processed to sulfuric acid or reduced to elemental sulfur. Ammonium sulfate produced in small amounts can be sold as fertilizer; however, as a major product, it would have a limited market and value.

Regeneration systems used by Cominco and others (17) employed distillation or a combination of distillation and acidification with sulfuric acid. These regeneration systems produce more ammonium sulfate than desired presently, and they appear to be more expensive than modified versions of the Hixon-Miller (15) regeneration scheme being tested by TVA.

Hixon acidified the rich absorber liquor to release sulfur dioxide according to the following equations.

$$NH_4HSO_3 + NH_4HSO_4 \longrightarrow (NH_4)_2SO_4 + SO_2 + H_2O \qquad (6)$$

$$(NH_4)_2SO_3 + 2NH_4HSO_4 \longrightarrow 2(NH_4)_2SO_4 + SO_2 + H_2O \qquad (7)$$

The reactions above produce ammonium sulfate and consume ammonium bisulfate. To avoid the net production of ammonium sulfate and to provide the needed ammonium bisulfate, Hixon decomposed ammonium sulfate to ammonium bisulfate according to the following equation.

$$(NH_4)_2SO_4 \longrightarrow NH_4HSO_4 + NH_3 \qquad (8)$$

This decomposition, demonstrated on a large scale during 1946, proceeds selectively as shown at about 725°F. The selective sulfate-bisulfate decomposition limits the net production of ammonium sulfate to that obtained by oxidation. Thus sulfur dioxide production is maximized by the Hixon acidification process.

A simplified flow sheet for the ammonia absorption - bisulfate regeneration process being piloted by TVA is shown in Figure 21. Several regeneration alternatives can be tested in this pilot plant. All of the alternatives produce crystals of ammonium sulfate for subsequent decomposition to ammonium bisulfate. Four process variations are being considered as follows.

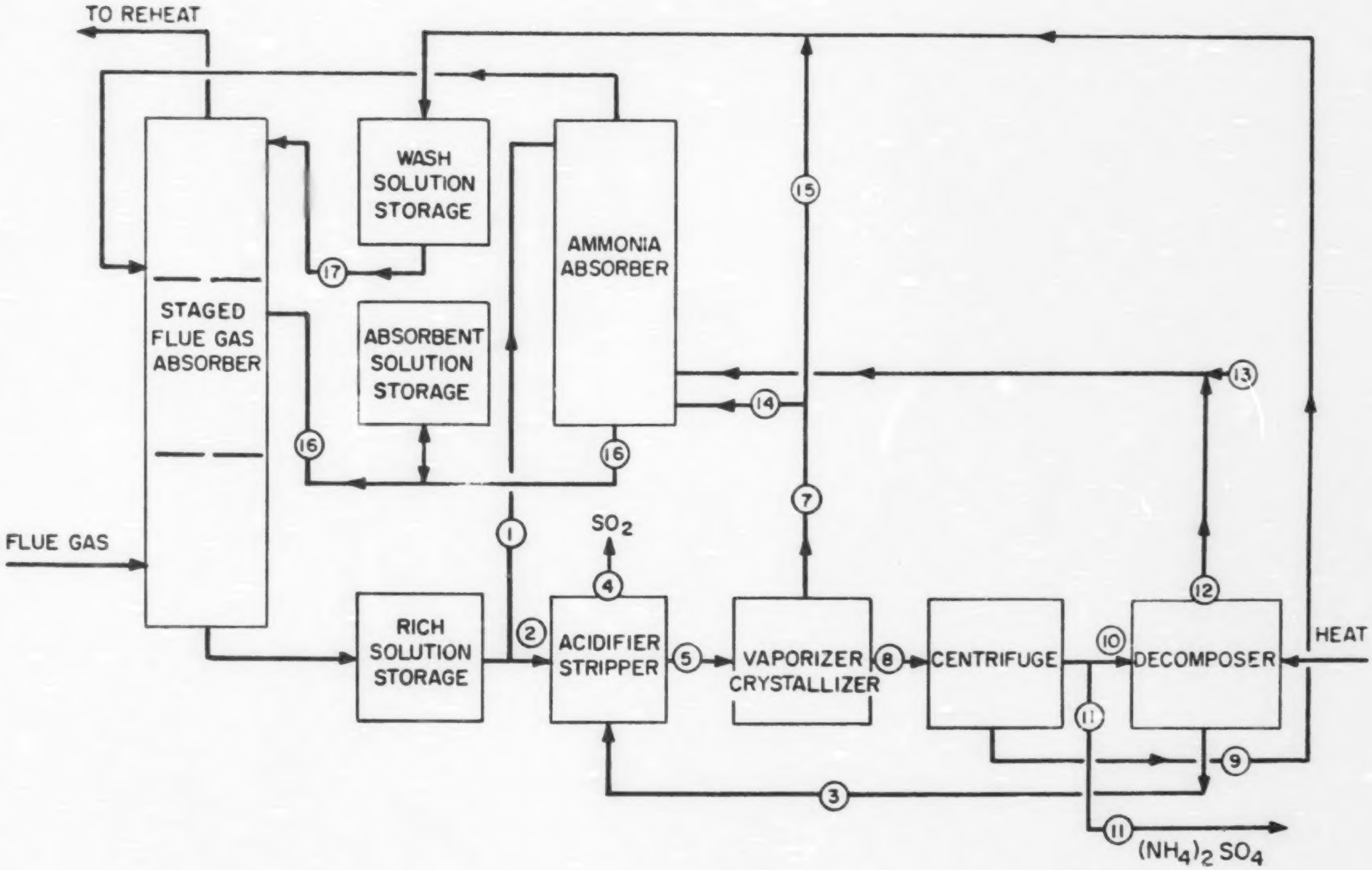

FIGURE 21

Flue Gas Desulfurization Ammonia System

1. Complete vaporization of water from the acidifier-stripper liquor.
2. Partial vaporization of water from the acidifier-stripper liquor.
3. No vaporization of water from the acidifier-stripper liquor.
    a. Absorber operated with an ammoniacal slurry of ammonium sulfate.
    b. Liquor saturated with ammonium sulfate at the absorber outlet.

Important process quantities are summarized in Table 6. Detailed calculation sheets for typical examples of these process variations are given as Tables 7 through 11. The stream quantities shown are identical with the streams identified by the same numbers on Figure 21. Gottfried's solubility data (18), shown in Figure 22, were used in all of the calculations except the variation involving complete vaporization of water.

These data show that:

1. The energy required for complete vaporization of water can be significantly higher than when the water is only partially vaporized in recovering crystalline ammonium sulfate—see Figure 23. If no water is vaporized, no energy is required for this purpose.
2. Equipment size and related investment cost are least for complete vaporization of water and highest for no vaporization of water if slurry formation in the absorber is avoided—see Figure 24. If slurry formation can be tolerated, intermediate size equipment may be practical.

Other factors that must be considered in evaluating the potentialities of process variations are included in Table 7. These are:

1. Buildup of soluble contaminants in the absorber liquor. This is least with complete vaporization of water.
2. Risk of ammonium sulfate scaling. This is also least with complete vaporization of water.
3. Risk of system plugging. This, too, is least with complete vaporization of water.

In view of the factors considered, complete vaporization of water appears to best combine operability and economy of operation. If initial operation with complete vaporization of water should reveal serious process limitations, other process variations can and will be tested.

TABLE 6

FLUE GAS DESULFURIZATION - AMMONIA SYSTEM:

RUN SUMMARIES FOR PROCESS VARIATIONS

Process variable	Variation 1 (Complete vaporization of water)	Variation 2 (Partial vaporization of water)	Variation 3 (No vaporization of water)	Variation 4 (No vaporization of water)
C_A	12.0	6.32	5.0	1.7
S/C_A	0.8	0.8	0.8	0.8
Absorber temp., °F	122	122	122	122
Crystallizer temp., °F	-	86	86	86
Free water in absorber as % of free water at saturation	236.0	110.0	(slurry operation)	100.0
Lb of solid $(NH_4)_2SO_4$/100 lb of saturated solution from absorber	-	-	6.84	-
$(NH_4)_2SO_4$ oxidation product, % of SO_x absorbed	10.0	10.0	10.0	10.0
Lb of water vaporized/lb of SO_2 released	2.9	1.65	0.0	0.0
Lb of absorber effluent processed/lb of SO_2 released	4.46	8.43	12.77	34.62
Solubility data	Gottfried	Gottfried	Gottfried	Gottfried

TABLE 7

AMMONIUM BISULFATE PROCESS REGENERATION SYSTEMS

Process variation	Estimated C_{max}	Absorber product liquor, % $(NH_4)_2SO_4$ saturation	Comments
1. (100% vaporization)	15	very low	Small regeneration equipment. Least buildup of soluble contaminants in absorber liquor. No possibility of $(NH_4)_2SO_4$ scaling.
2. (partial vaporization)	11	91	Larger regeneration equipment. Potential for soluble contaminant buildup. Low risk of $(NH_4)_2SO_4$ scaling.
3. (no vaporization)	5	slurry operation	Economically most attractive if operable at C of 5 or greater. Soluble contaminant buildup. Highest risk of $(NH_4)_2SO_4$ scaling. High risk of system plugging.
4. (no vaporization)	2	100	Largest regeneration equipment. Soluble contaminant buildup. High risk of $(NH_4)_2SO_4$ scaling. Large pumping requirement.

TABLE 7

AMMONIUM BISULFATE PROCESS REGENERATION SYSTEMS

Process variation	Estimated C_{max}	Absorber product liquor, % $(NH_4)_2SO_4$ saturation	Comments
1. (100% vaporization)	15	very low	Small regeneration equipment. Least buildup of soluble contaminants in absorber liquor. No possibility of $(NH_4)_2SO_4$ scaling.
2. (partial vaporization)	11	91	Larger regeneration equipment. Potential for soluble contaminant buildup. Low risk of $(NH_4)_2SO_4$ scaling.
3. (no vaporization)	5	slurry operation	Economically most attractive if operable at C of 5 or greater. Soluble contaminant buildup. Highest risk of $(NH_4)_2SO_4$ scaling. High risk of system plugging.
4. (no vaporization)	2	100	Largest regeneration equipment. Soluble contaminant buildup. High risk of $(NH_4)_2SO_4$ scaling. Large pumping requirement.

TABLE 8

FLUE GAS DESULFURIZATION - AMMONIA SYSTEM

PROCESS VARIATION 1 (COMPLETE VAPORIZATION OF WATER)

	Stream No.						
	1	2	5	8	9	16	17
Temperature, °F	122	122				122	122
Pound mols/hr							
$(NH_4)_2SO_4$ (in soln.)	2.0939	1.0667	13.0667			2.0939	
$(NH_4)_2SO_4$ (solid)				13.0667			
$(NH_4)_2SO_3$	4.7111	2.4000	0.0000			18.8445	
NH_4HSO_3	14.1334	7.2000	0.0000				
Free water	175.3588	89.3333	98.9333			210.6683	
Total water	196.2972	100.0000					
Free water in solution as % of free water at saturation	236	236	slurry				
Salt, % by wt. of solution or slurry	41.31	41.31	49.20			39.73	
C_A		12					
S/C_A		0.8					

	Pound mols/hr				
Stream No.	NH_4HSO_4	SO_2	NH_3	H_2O	$(NH_4)_2SO_4$
3	12.0				
4		9.6			
7				98.9333	
10					12.0000
11					1.0667
12			12.0000		
13			2.1334	1.0667	
14				34.2429	
15				64.6904	

TABLE 9

FLUE GAS DESULFURIZATION - AMMONIA SYSTEM

PROCESS VARIATION 2 (PARTIAL VAPORIZATION OF WATER)

	Stream No.						
	1	2	3	8	9	16	17
Temperature, °F	122	122	-	86	86	122	122
Pound mols/hr							
$(NH_4)_2SO_4$ (in soln.)	22.335	11.378	21.378	10.489	10.489	22.335	10.489
$(NH_4)_2SO_4$ (solid)	0.000	0.000		10.889			
$(NH_4)_2SO_3$	3.926	2.000	0.000			15.704	
NH_4HSO_3	11.778	6.000	0.000				
Free water	272.561	138.849	146.849	100.000	100.000	278.489	141.810
Total water	310.600	158.227					
Free water in solution as % of free water at saturation	110	110	slurry	slurry	100	110	156
Salt, % by wt. of solution or slurry	48.22	48.22	5.163	61.05	43.48	48.76	35.17
C_A		6.32					
S/C_A		0.8					

	Pound mols/hr				
Stream No.	NH_4HSO_4	SO_2	NH_3	H_2O	$(NH_4)_2SO_4$
3	10.0				
4		8.0			
7				46.849	
10					10.000
11					0.889
12			10.0		
13			1.778	0.889	
14				5.039	
15				41.810	

TABLE 10

FLUE GAS DESULFURIZATION - AMMONIA SYSTEM

PROCESS VARIATION 3 (NO VAPORIZATION OF WATER)

	Stream No.						
	1	2	5	8	9	16	17
Temperature, °F	122	122		86	86	122	122
Pound mols/hr							
$(NH_4)_2SO_4$ (in soln.)	16.313	8.311	14.896	9.452	9.452	15.691	9.452
$(NH_4)_2SO_4$ (solid)	3.111	1.585		5.444		3.733	
$(NH_4)_2SO_3$	1.963	1.000	0.000			7.852	
NH_4HSO_3	5.889	3.000	0.000			0.000	
Water	169.017	86.104	90.104	90.104	90.104	169.461	90.104
	196.293	100.000					
Pound of solid $(NH_4)_2SO_4$/100 lb saturated solution	6.84	6.84	-	25.04	0	817	0
Salt, wt. % of solution or slurry	52.60	52.60	54.80	54.80	43.48	53.25	43.48
C_A		5.0					
S/C_A		0.8					

	Pound mols/hr				
Stream No.	NH_4HSO_4	SO_2	NH_3	H_2O	$(NH_4)_2SO_4$
3	5.0				
4		4.0			
7			0	0	
10					5.000
11					0.444
12			5.000		
13			0.889	0.444	
14			0	0	
15				0	

TABLE 11

FLUE GAS DESULFURIZATION - AMMONIA SYSTEM

PROCESS VARIATION 4 (NO VAPORIZATION OF WATER)

	Stream No.						
	1	2	5	8	9	16	17
Temperature, °F	122	122	-	86	86	122	122
Pound mols/hr							
$(NH_4)_2SO_4$ (in soln.)	18.904	9.630	11.330	9.479	9.479	18.904	9.749
$(NH_4)_2SO_4$ (solid)	0.000	0.000		1.851			
$(NH_4)_2SO_3$	0.667	0.340	0.000			2.669	
NH_4HSO_3	2.002	1.020	0.000				
Free water	174.727	89.010	90.370	90.370	90.370	174.878	90.370
Total water	196.300	100.000					
Free water in solution as % of free water at saturation	100	100	Slurry	Slurry	100	100	110
Salt, % by wt. of solution or slurry	46.84	46.84	47.90	47.90	43.48	47.12	43.48
C_A		1.70					
S/C_A		0.8					

	Pound mols/hr				
Stream No.	NH_4HSO_4	SO_2	NH_3	H_2O	$(NH_4)_2SO_4$
3	1.7				
4		1.36			
7				0	
10					1.7
11					0.1511
12			1.7		
13			0.3022	0.1511	
14				0	
15				0	

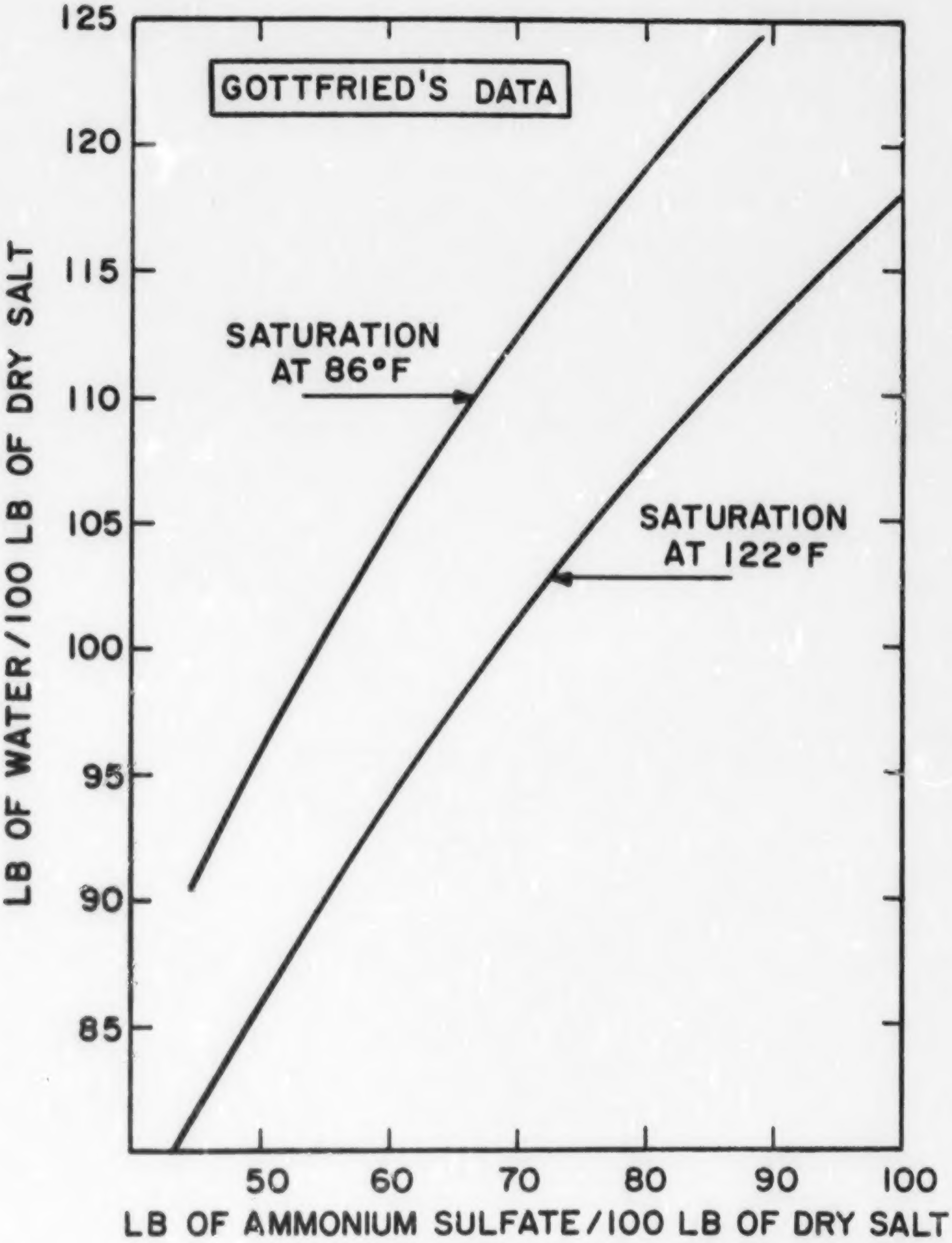

FIGURE 22

Solubility Data for the System

$(NH_4)_2SO_4 - (NH_4)_2\ SO_3 - NH_4SO_3 - H_2O$

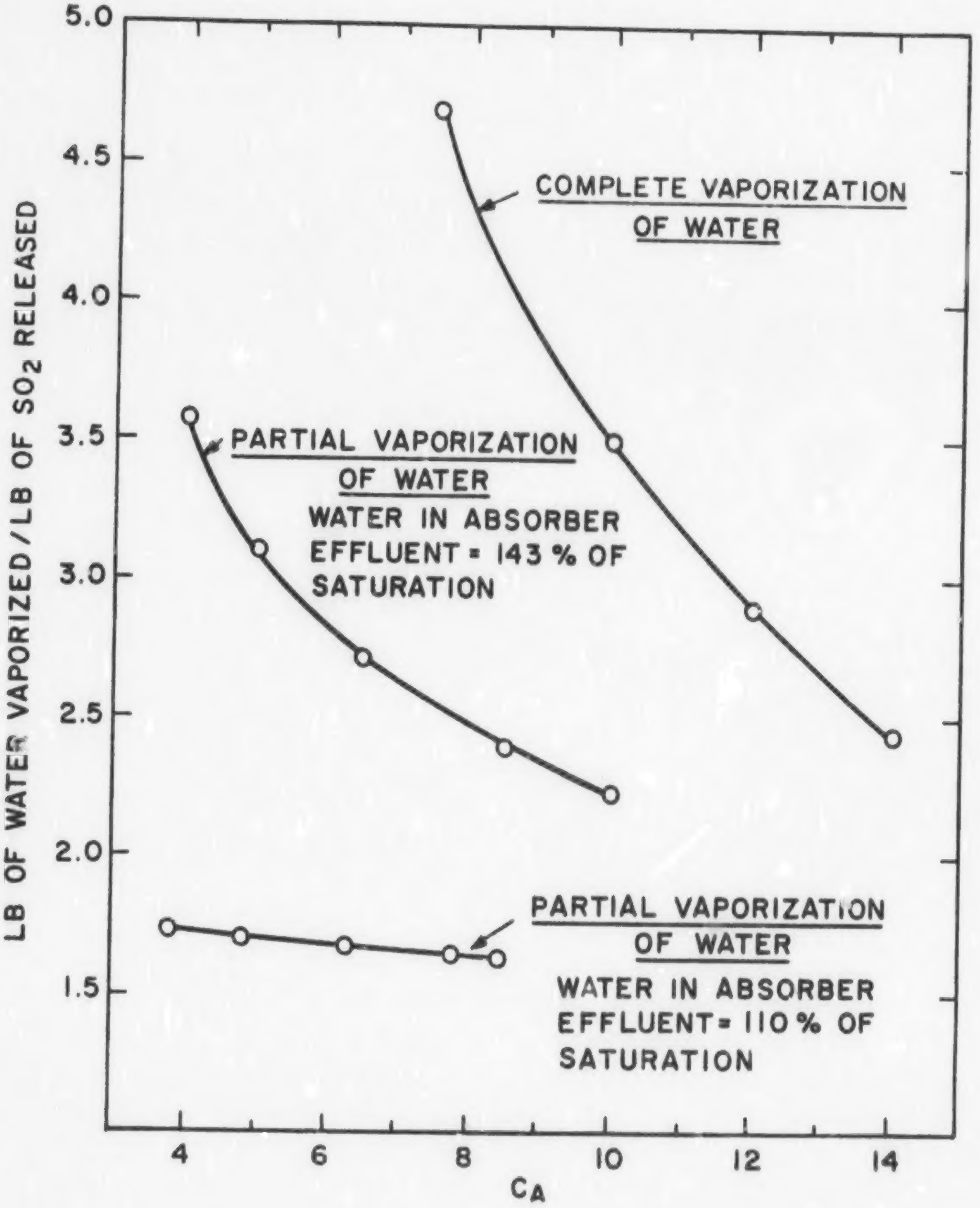

FIGURE 23

Bisulfate Regeneration of Ammoniacal Sulfite Solutions

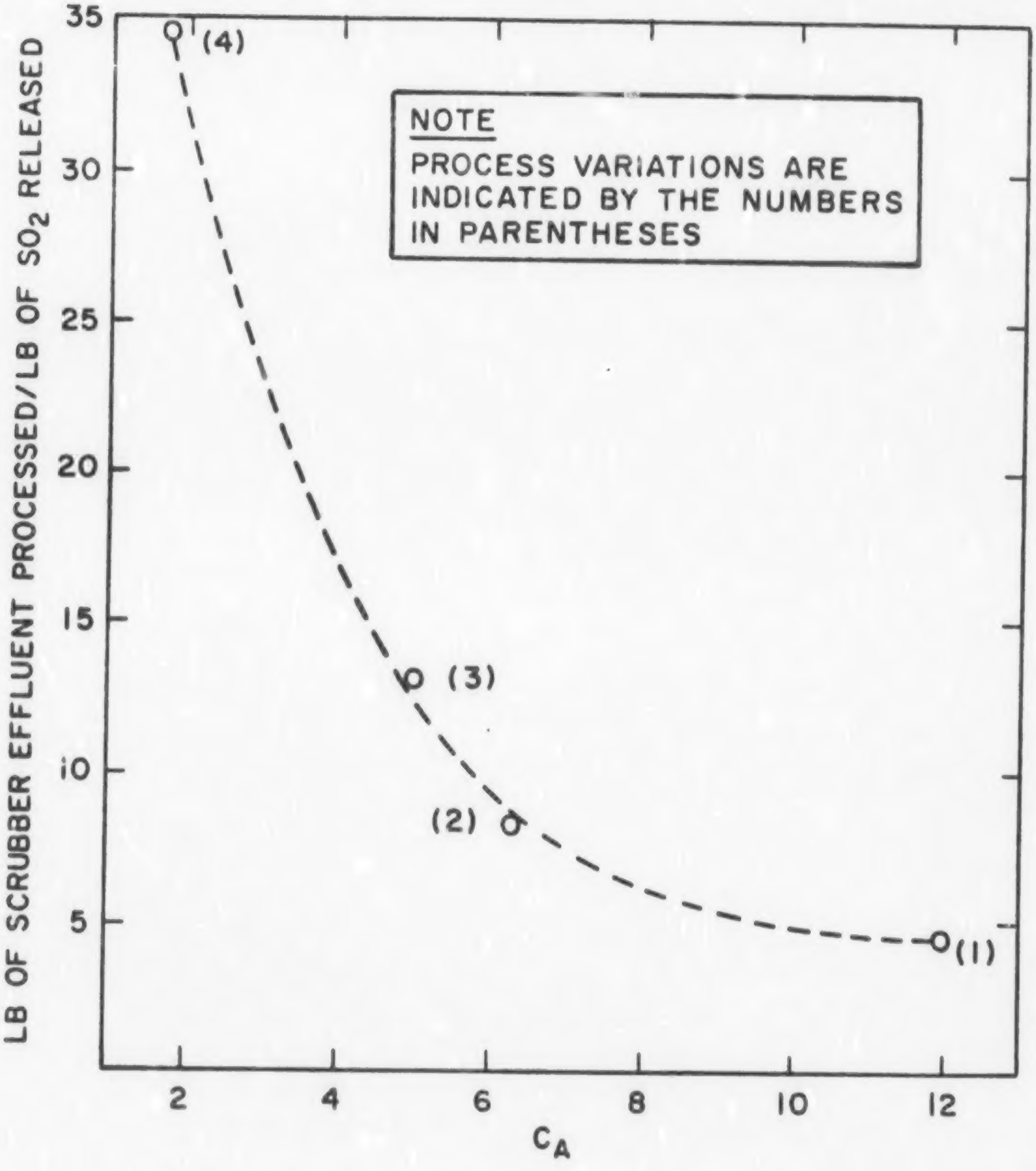

FIGURE 24

Bisulfate Regeneration of Ammoniacal Sulfite Solutions for Different Process Variations

APPENDIX B - EQUIPMENT EVALUATION

Equipment for Pilot Plants

Ductwork for Pilot Plant No. 1: No maintenance was required on the 14-inch rigid mild steel ductwork. Although during the early part of each pilot-plant run, the temperature of the duct was below the dew point of the SO_3 in the flue gas, deposits of fly ash corrosion products protected the duct from failure due to acid condensation. The flexible duct became nearly inflexible making it difficult to move from one position to another; also, after the duct had been moved a number of times, the flanges failed which caused excessive air leaks. This system was replaced by a system of rigid ductwork and blanks.

Ductwork for Pilot Plant No. 2: Rigid mild steel ductwork was used throughout; no maintenance was required.

Heat Exchanger for Pilot Plant No. 1 Only: The heat exchanger used for cooling inlet flue gas to the scrubber was furnished by Thermal Transfer Corporation. The exchanger consisted of three 32-by 32-inch flanged sections (Fig. 25). Each section contained 825 linear feet of 3/4-inch pipe with a total tube surface area of 681 square feet. The shell and tubes were made of mild steel. Hot flue gas passed through the shell side and water, the cooling medium, through the tubes.

Deposits of scale, fly ash, and ammonium salts on the tubes (Fig. 26) eventually restricted the gas flow through the shell. The ammonium salts resulted from injecting a small amount of gaseous ammonia upstream from the heat exchanger for SO_3 corrosion control. Soot blowers (Diamond Power Speciality Corporation) (Fig. 27) provided with the unit to remove these deposits did not perform properly because of an insufficient steam pressure available at the plant. (A steam supply at a pressure of 600 psig was specified by the manufacturer; the steam available to the plant was at a static pressure of 350 psig and 50 psig during operation of the blowers.) The exchanger was cleaned by washing the tubes with a jet of high-pressure water (Fig. 28). After about 1500 hours of operation, the continual removal of the protective deposits caused a leak to develop in the top section of the tubes. This section was bypassed for the remainder of the tests.

Cyclone Dust Collectors for Pilot Plant No. 1 Only: Two cyclonic collectors were used in the pilot-plant operations (Fig. 29). One of the dust collectors had a collection efficiency of about 70% to simulate the flue dust loadings from power plants using mechanical collectors. The other dust collector had a 95% dust-collection efficiency to approximate flue gas dust loadings from power plants using electrostatic precipitators. No buildup of solids was observed in either insulated mild steel dust collector. The collected fly ash was discharged from the cyclones with difficulty.

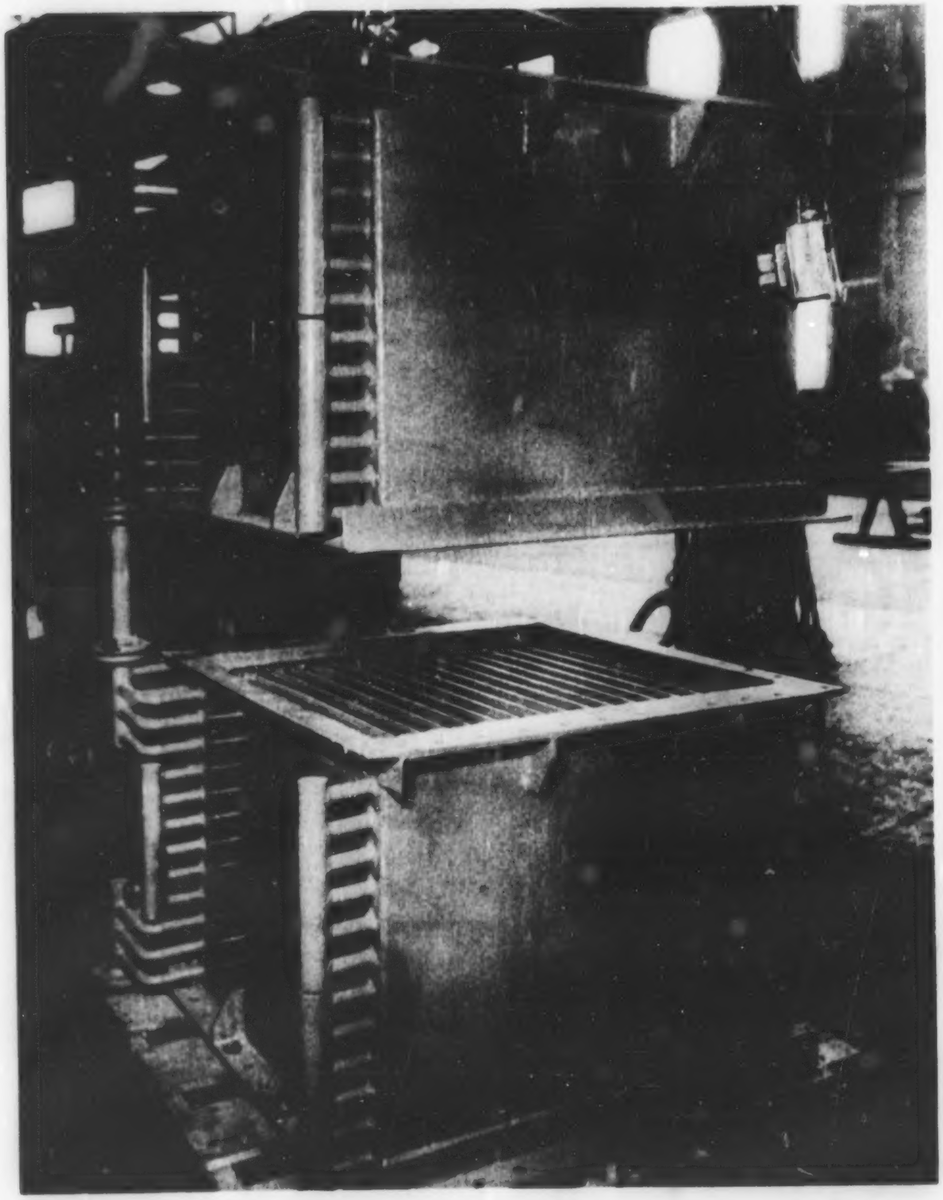

FIGURE 25

Heat Exchanger Tube Sections

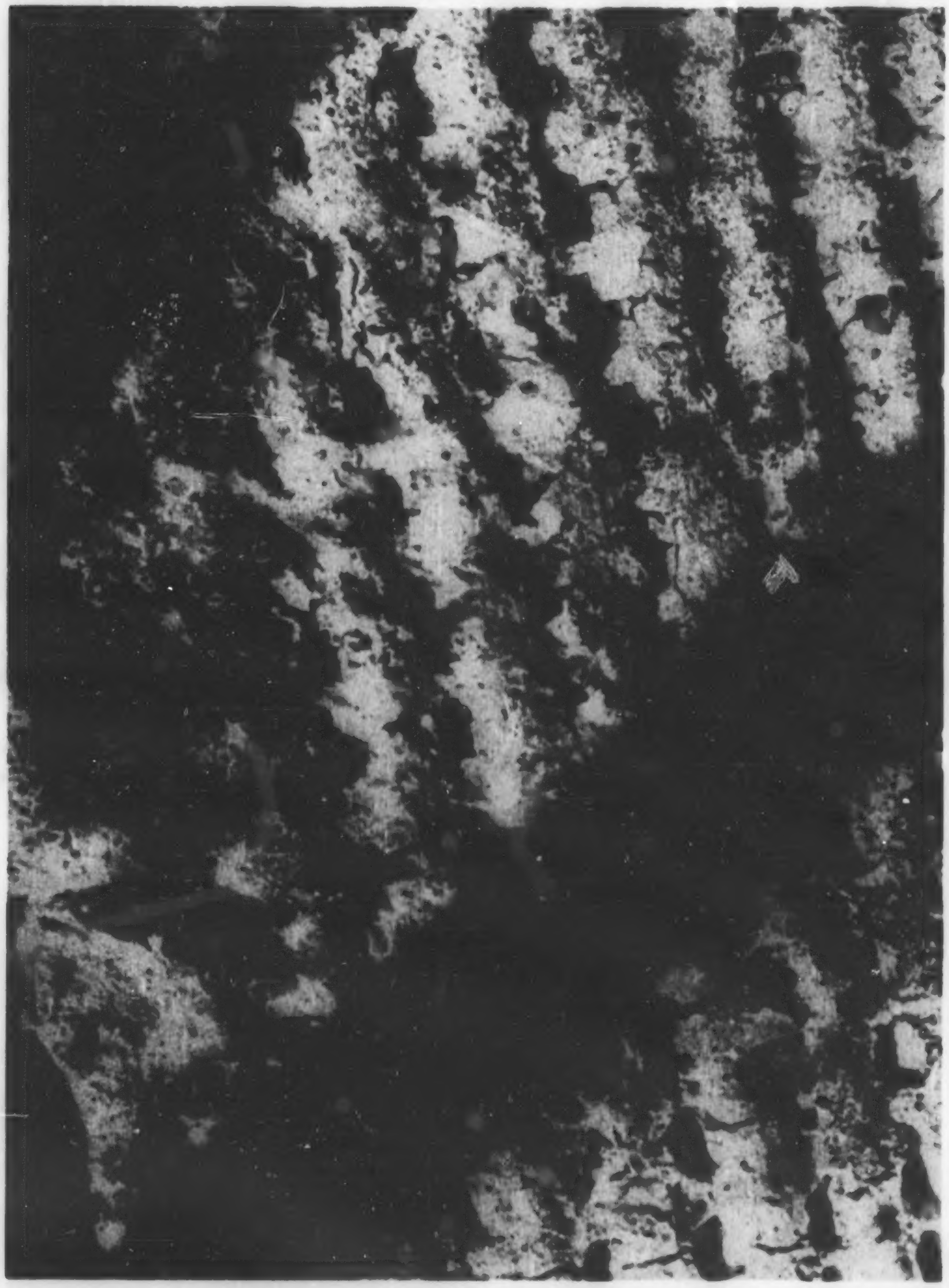

FIGURE 26

Deposits of Scale and Fly Ash on Heat Exchanger Tubes

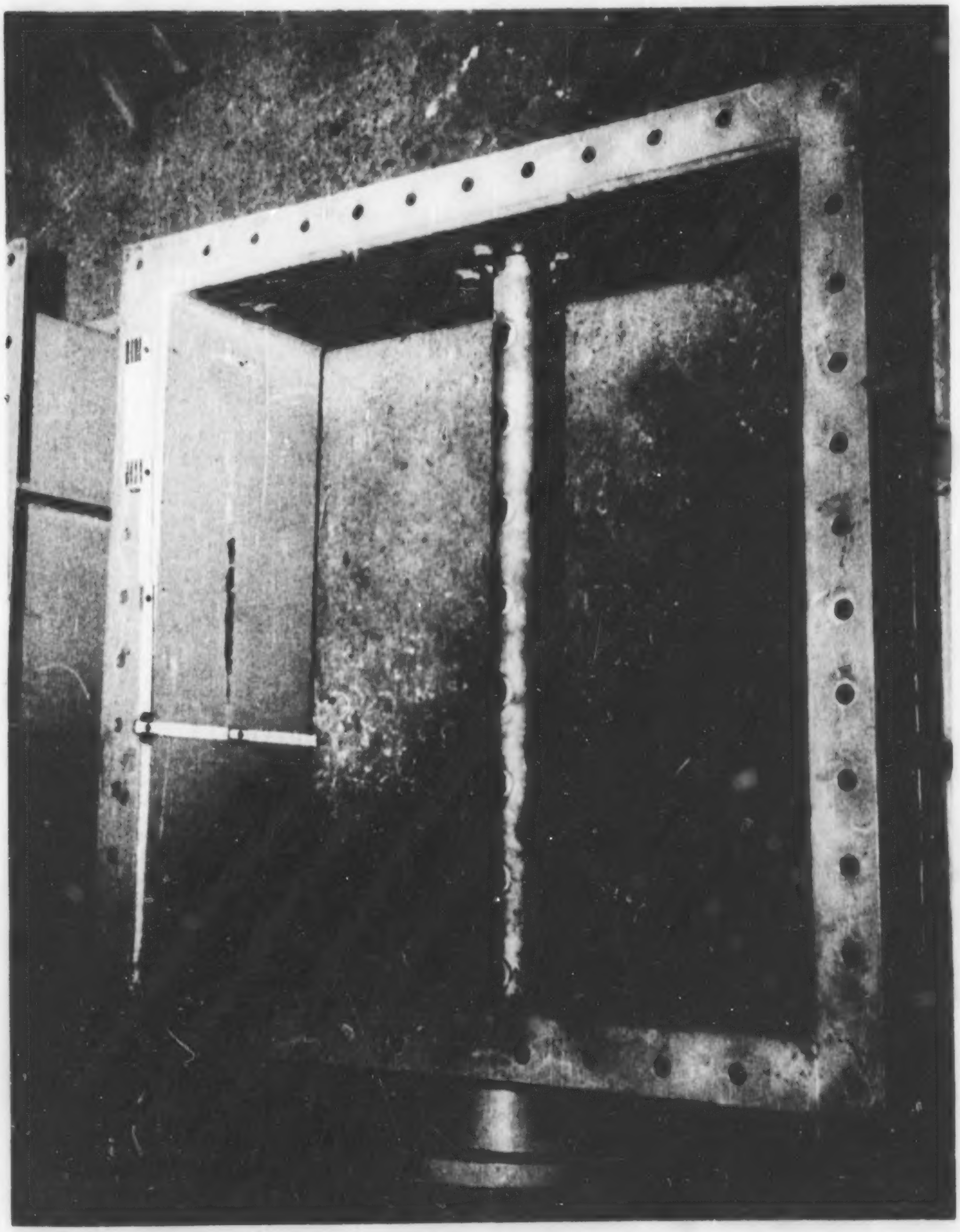

FIGURE 27

Soot Blower for Cleaning Heat Exchanger Tubes

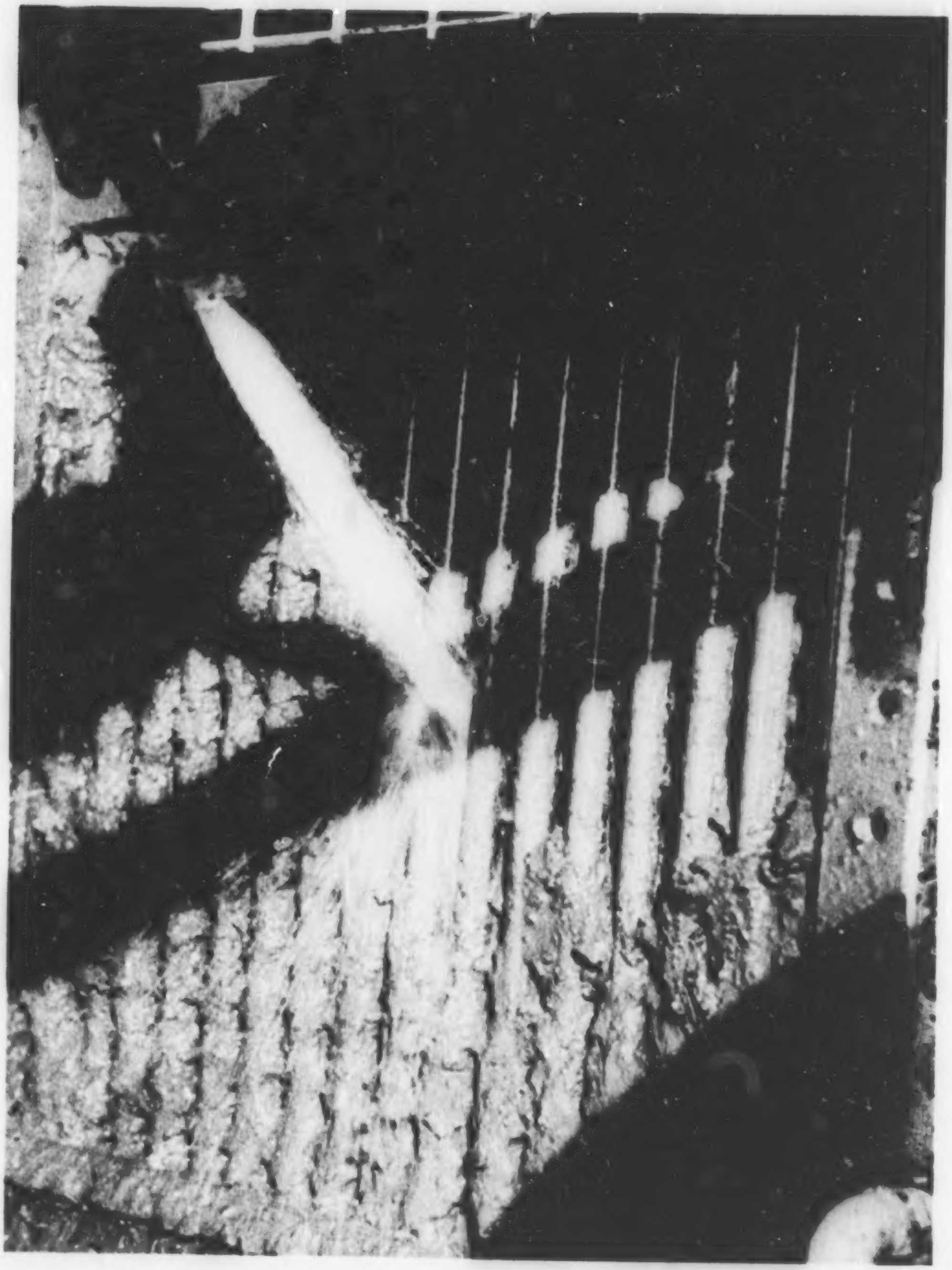

FIGURE 28

Cleaning Heat Exchanger Tubes with Water

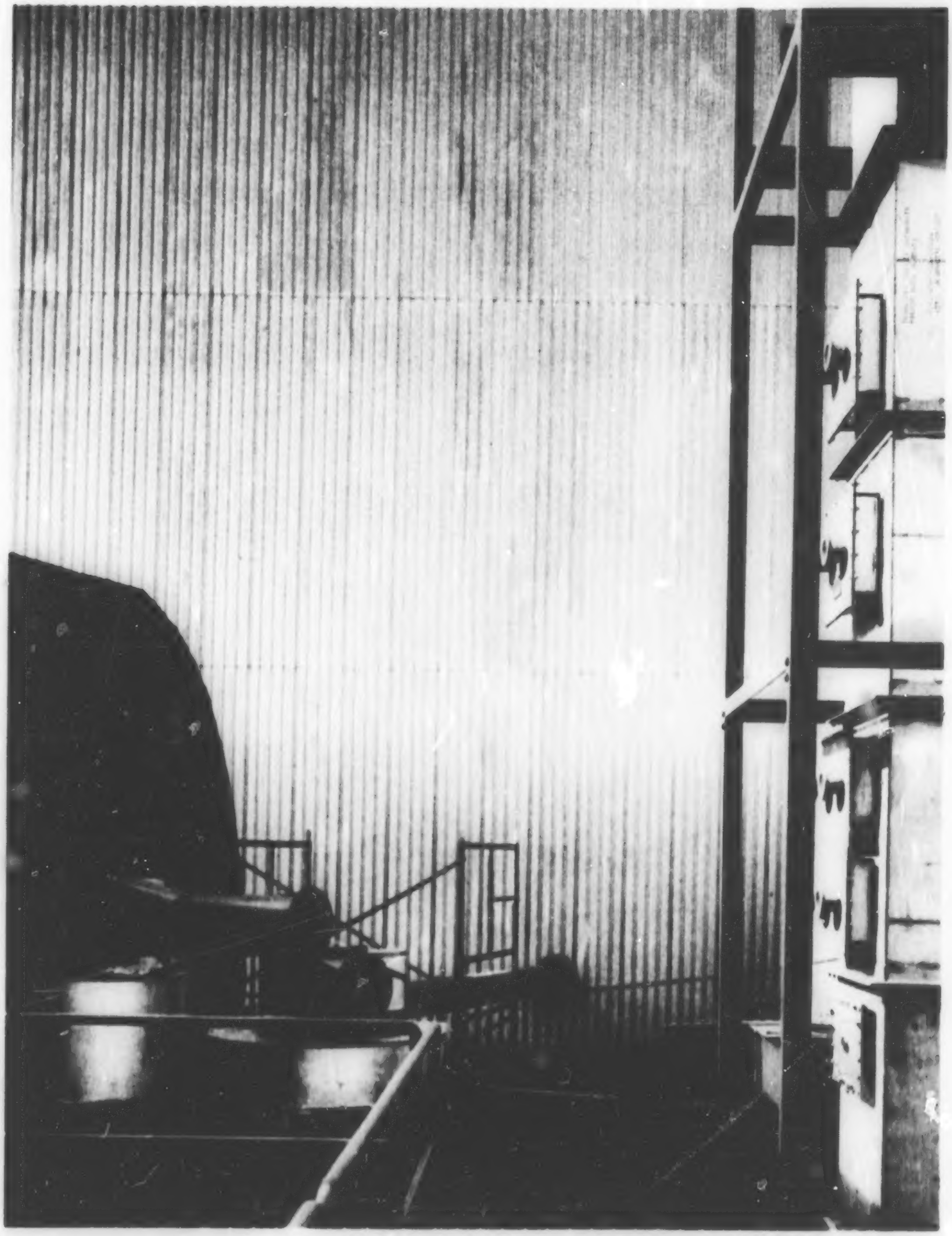

FIGURE 29

Cyclonic Dust Collectors for Pretreating Flue Gas

Absorbers for Pilot Plant No. 1: The absorbers tested consisted of three sections or elements, plus a gas inlet and outlet assembly. The three sections were removable and contained the various absorber and mist elimination elements. Each of the original absorber sections was 32 inches by 32 inches by 4 feet high. The first absorber tested was a sieve-tray type (Sly Impingjet)(Figs. 30 and 31). The absorber was designed to have independent absorbing stages and liquor recirculation loops. Interstage mixing of the absorber liquors occurred during operation. A portion of the liquor on the lower stage was entrained as mist in the gas stream and was carried to the stage above. The carryover rate was intolerable in this study that required control of liquor rates and concentrations in each absorber circuit. The manufacturer concluded that the gas velocity through the absorber elements was too high. At their suggestion, two vane-type mist eliminators were installed—one between the bottom and middle tray, and one between the middle and top tray. The modifications failed to reduce the interstage mixing to an acceptable level. Absorber operation was considered poor.

The sieve-tray absorber was replaced with a moving marble-bed absorber (National Dust Collector—Hydro-Filter) (Figs. 32 and 33). About 4 inches of 3/4-inch glass marbles was used on each tray. With this absorber, some leakage of the liquor to the lower trays occurred. This problem was corrected by adjusting liquor depth on each tray. The performance was generally good; consequently most of the test program was carried out using the marble-bed absorber.

A modified version of the sieve-tray absorber (Fig. 34), designed by the vendor, was installed. To solve the interstage liquor mixing problem a ballooned section was added between the bottom and middle trays and between the middle and top trays.

Operation of the absorber was good although the SO_2 removal efficiency was lower than with the marble-bed unit operating under similar conditions.

Absorber for Pilot Plant No. 2: The marble-bed (NDC) absorber was selected for use in the second pilot plant. The problems encountered with the absorber in the new location were (1) the absorber trays leaked to the tray below and (2) the marble beds plugged when a slurry of scrubbing liquor, ammonium sulfate, and fly ash was circulated through the absorber. The leakage was stopped by balancing the gas and liquor flows through the absorber. Slurry operation was discontinued after a few tests. The overall operation of the absorber was good.

The Koch tray which replaced the bottom marble-bed stage performed well as an SO_2 absorber and required no maintenance.

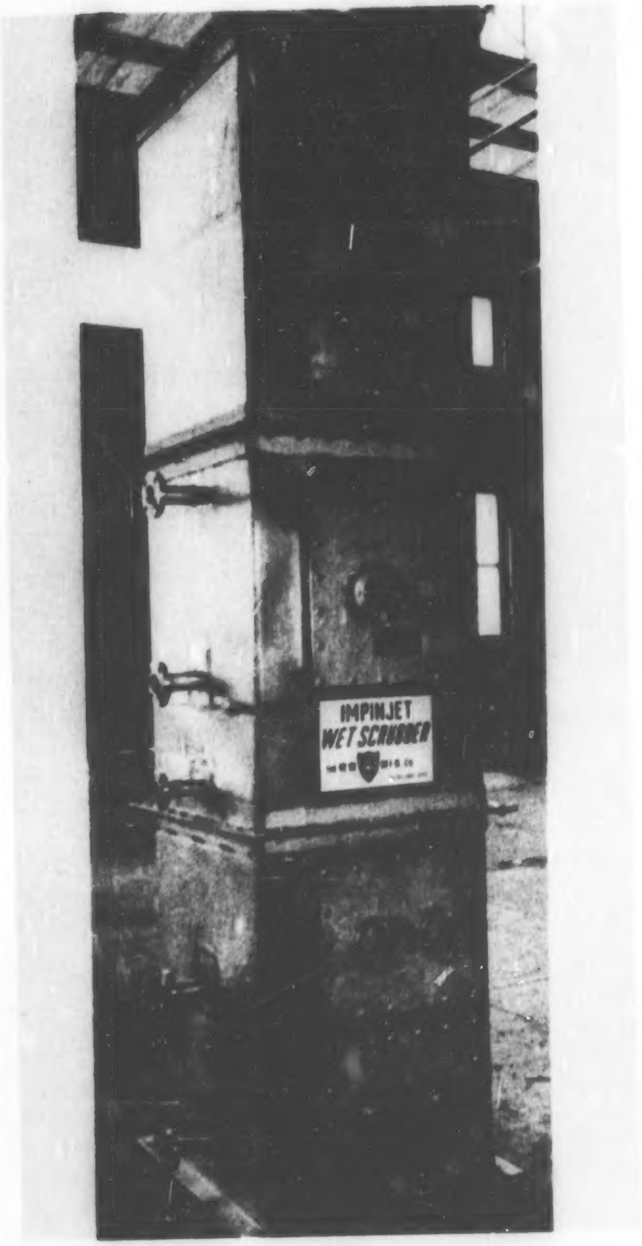

FIGURE 30

Overall View of Sieve-Tray Absorber

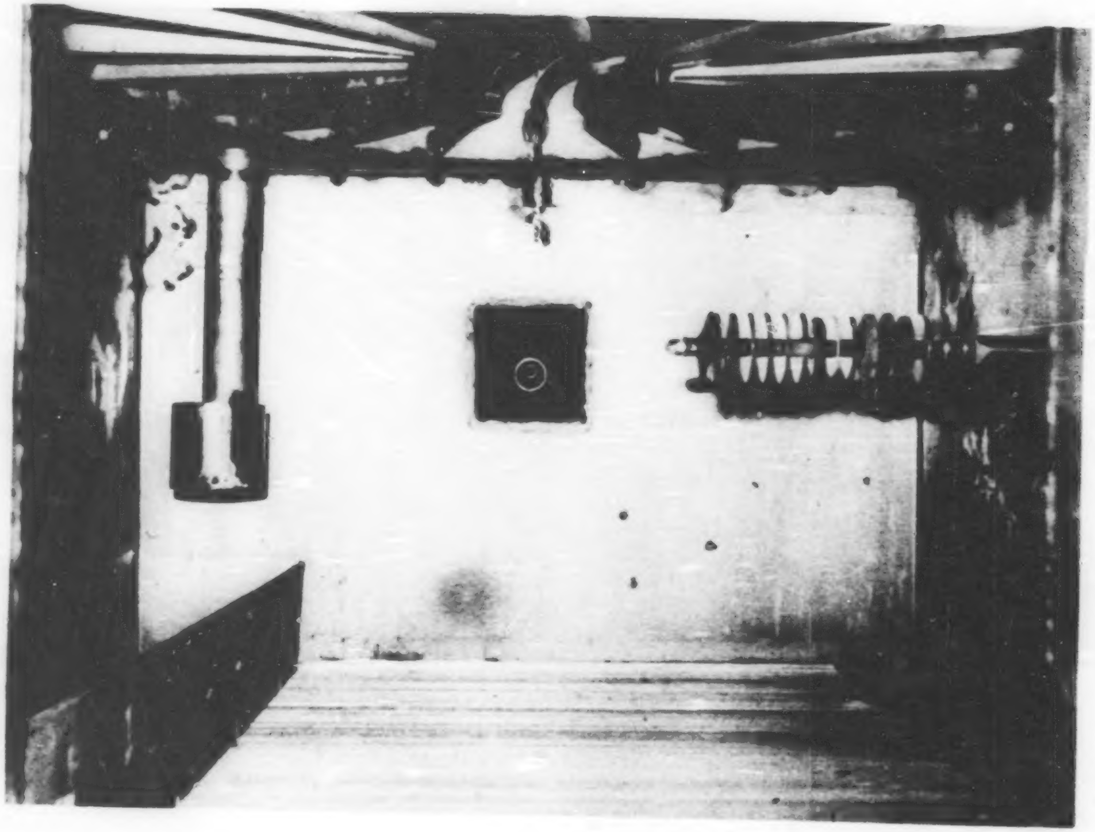

FIGURE 31

Internal View of Sieve-Tray Absorber

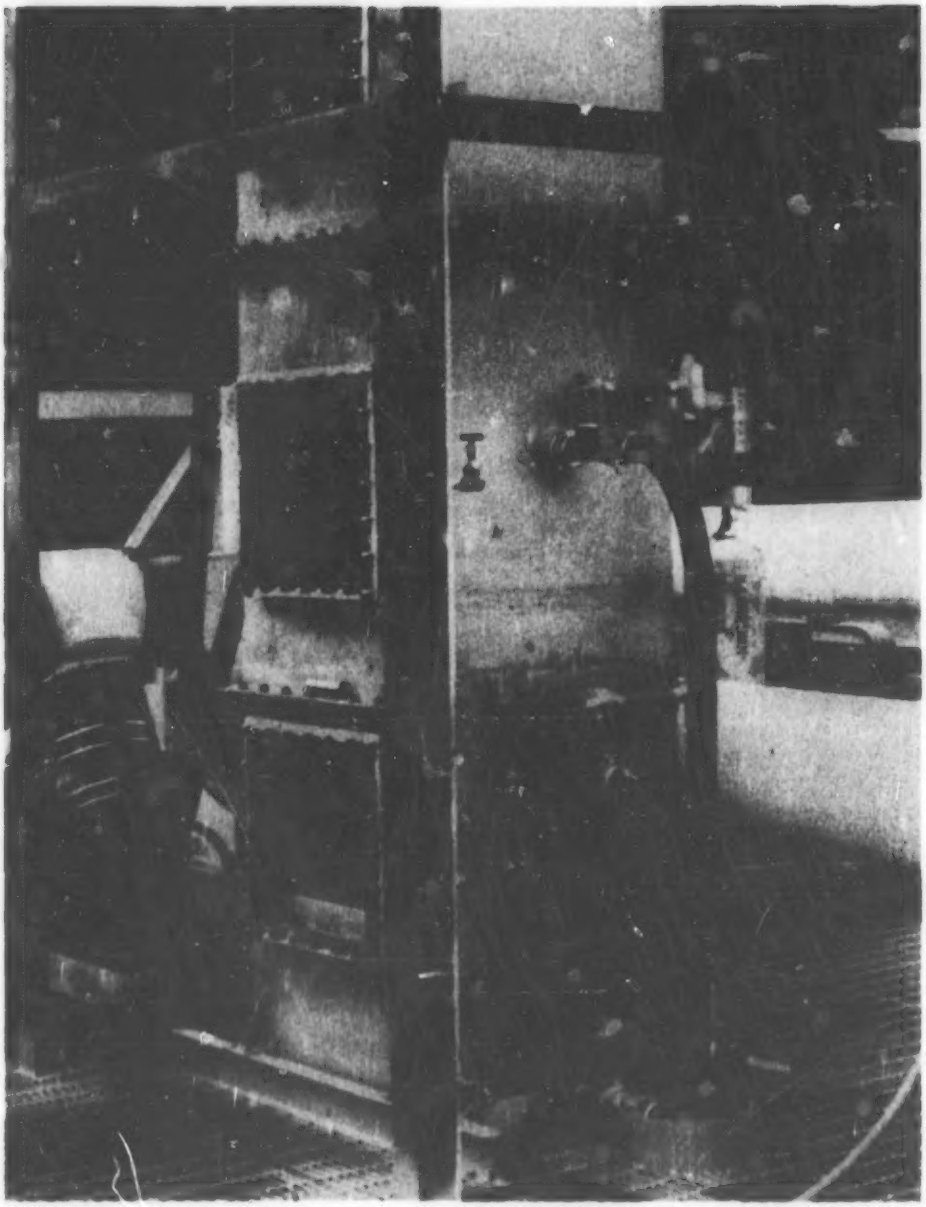

FIGURE 32

Overall View of Marble-Bed Absorber

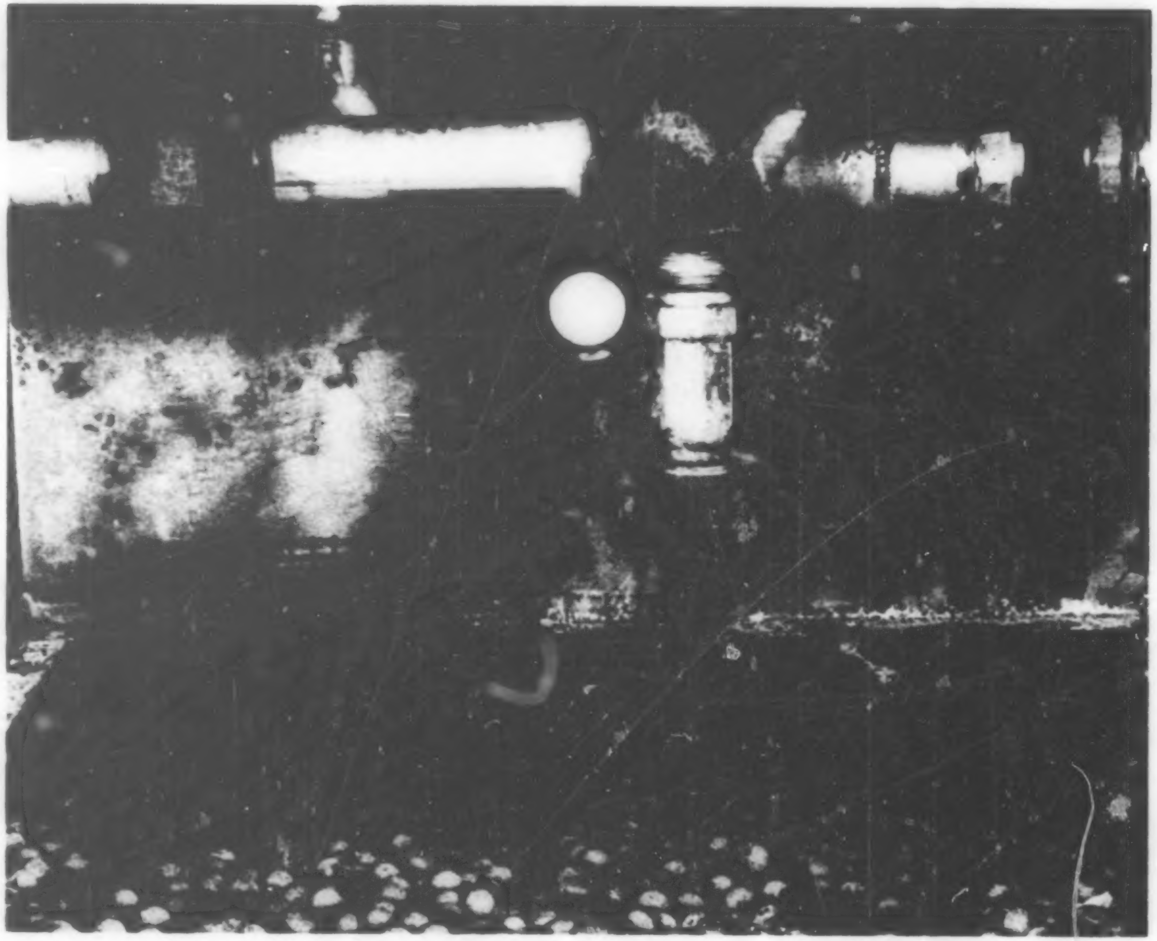

FIGURE 33

Internal View of Marble-Bed Absorber

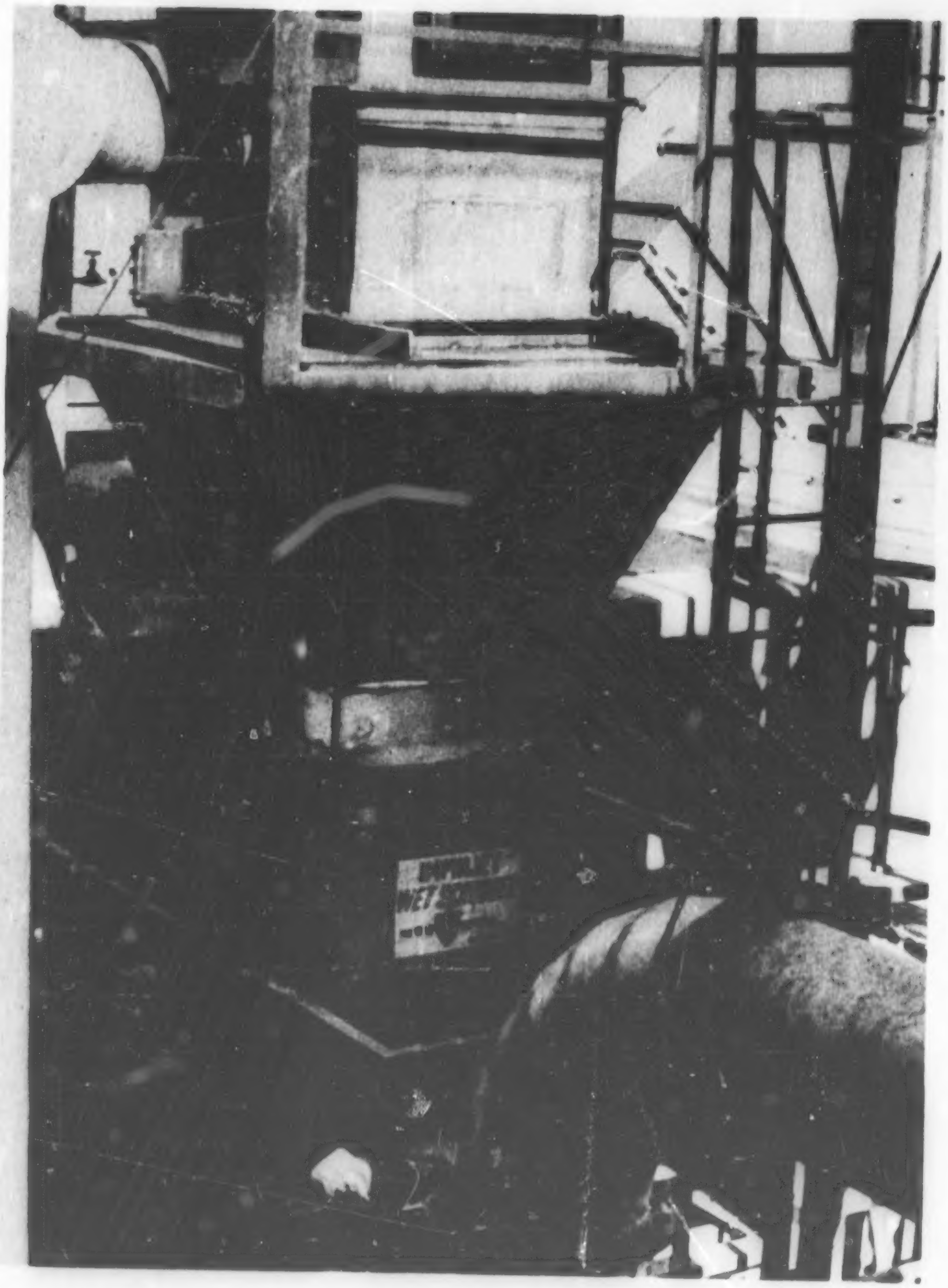

FIGURE 34

Modified Sieve-Tray Absorber

Blower System for Pilot Plant No. 1: Flue gas was moved through the system by two fans (American-Standard)(Fig. 35) installed in series. The fans (made of Type 304 stainless steel) were located after the absorber. One fan, equipped with a variable-speed drive (American-Standard), discharged into the suction of the second fan equipped with a constant-speed drive. Control of the gas flow using this system was excellent; a constant gas flow was maintained regardless of the drop across the absorber system. The main problem with the fans was the misalignment of the bearings which caused excessive vibration. The misalignment occurred when fly ash deposits built up on the fan housings and impellers and also when accumulated fly ash fell from the duct walls and hit the fan impeller. Three sets of bearings were replaced on each of the fans. The bearing pedestals, as received from the factory, were too lightweight for the vibration. The pedestals cracked and were repaired and strengthened. The blades on the impellers of both blowers required balancing several times. The belt drives gave no trouble. The variable-speed fluid drive used on the first fan (J-6) gave excellent service.

Blower System for Pilot Plant No. 2: Three blowers (same size and description as those on pilot plant No. 1) were used to move flue gas in the second pilot plant. Two constant-speed blowers were located upstream of the absorber (hot, dry gas) and one variable-speed blower was located after the absorber (cool, wet gas). The blowers were operated so that the bottom of the absorber was under a slight pressure and the top under a slight vacuum. No problems occurred with any of the fans during the 1100 hours of total operation.

Pumps for Pilot Plant No. 1: Pumps from two manufacturers were installed in the first pilot plant—three Allen-Sherman-Hoff centrifugal pumps (J-1, J-2, and J-9) and three Wilfley centrifugal pumps (J-3, J-4, and J-5).

Two Allen-Sherman-Hoff pumps (J-1 and J-2) (Fig. 36), driven by variable-speed fluid drives (American-Standard), were used in the pumping circuits to the bottom and middle absorber stages. These pumps had removable soft rubber linings and rubber-coated impellers. Very little wear was noted to either the rubber linings or the impellers (Fig. 37) after about 2500 hours of operation. One lining was damaged by a tramp metal but did not require replacing. The main problems encountered with these pump units were the failures of the small control motors to the variable-speed drives and the mechanical linkages from the drive to the control motors. The third rubber-lined Allen-Sherman-Hoff (J-9) pump gave excellent service in general use.

The three Wilfley centrifugal pumps made of Type 316L steel (J-3, J-4, and J-5) (Fig. 38) were used to recirculate liquor to the top absorber stage, to pump product liquor, and to pump forward feed solution to the system. Some leakage occurred around the shaft when liquor with a high specific gravity (1.25) was pumped. Some of the mechanical seals stuck because of solids. The overall pumping service was considered excellent.

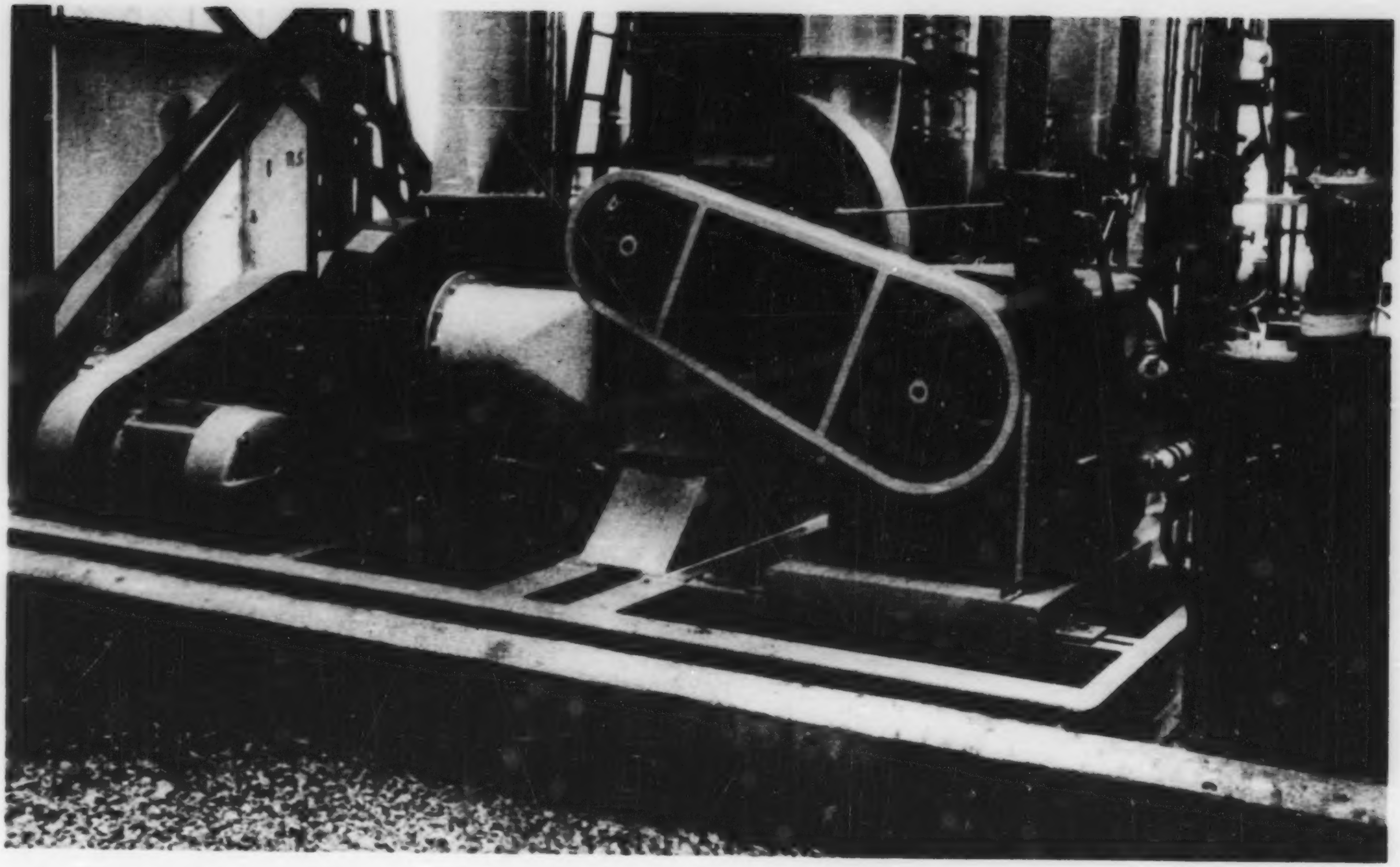

FIGURE 35

Pilot-Plant Blower System (J-5 and 6)

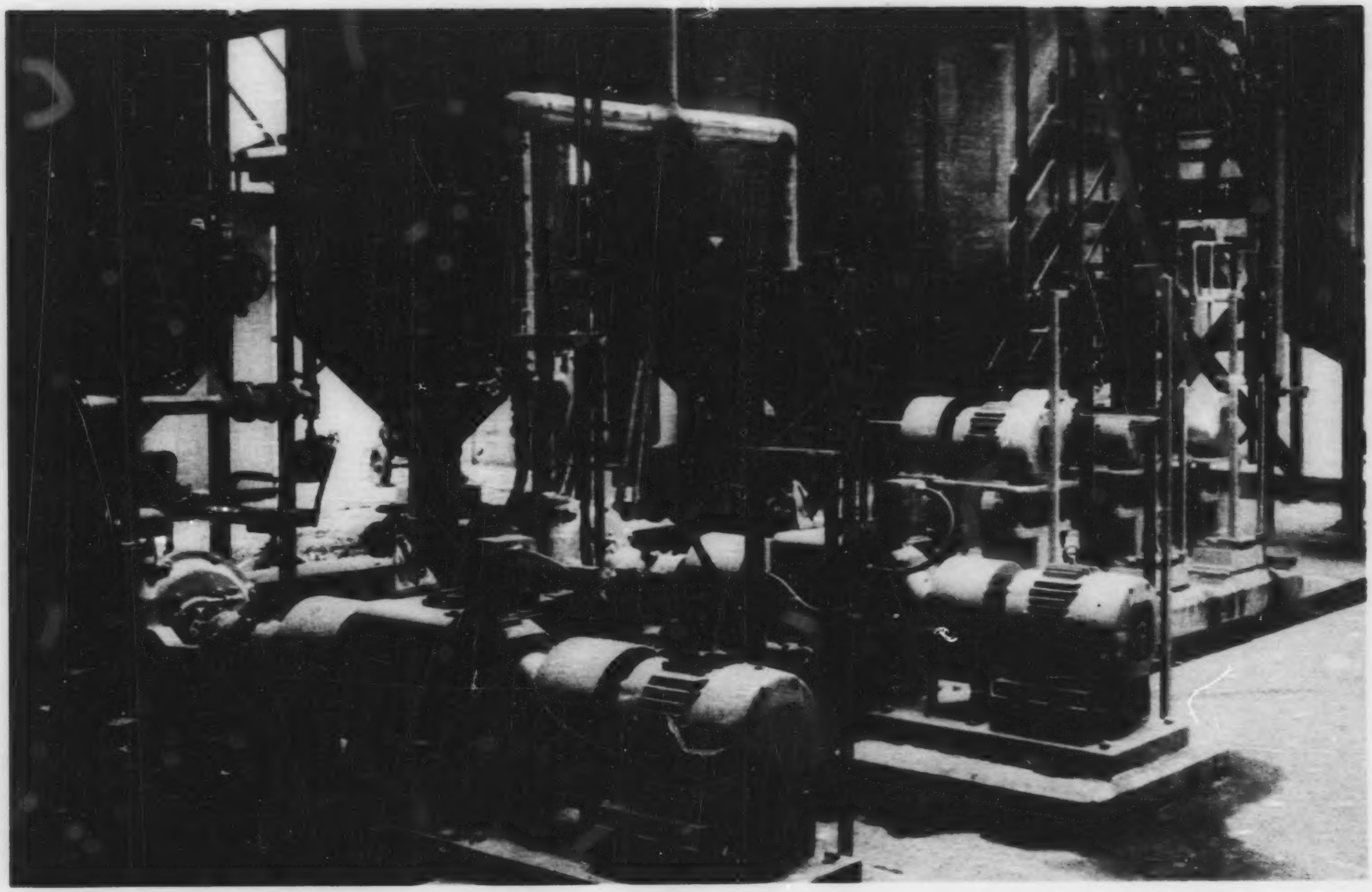

FIGURE 36

Variable-Speed, Rubber-Lined Pumps (J-1 and 2)

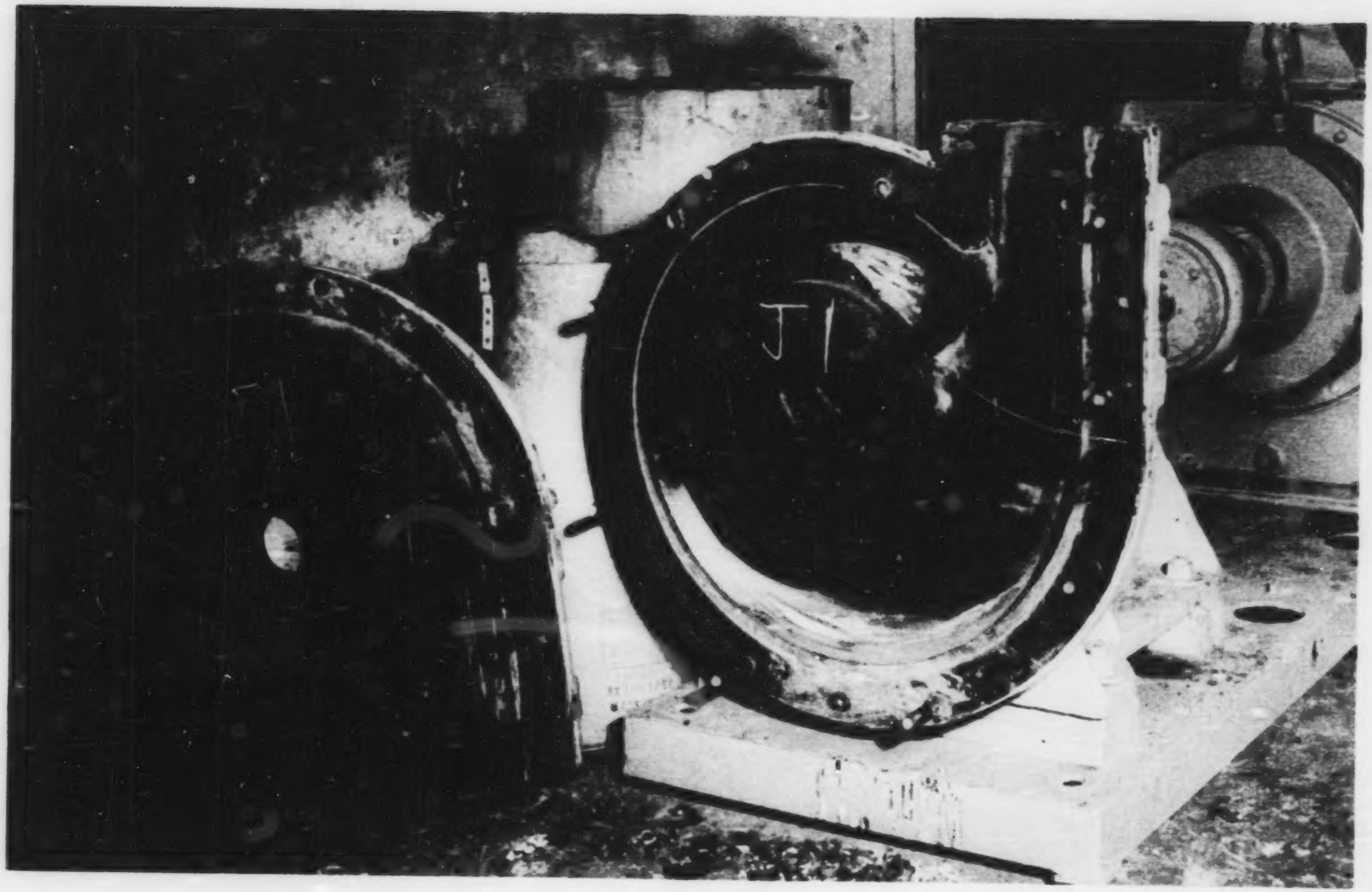

FIGURE 37

Rubber Liner in Pump After 2500 Hours of Operation

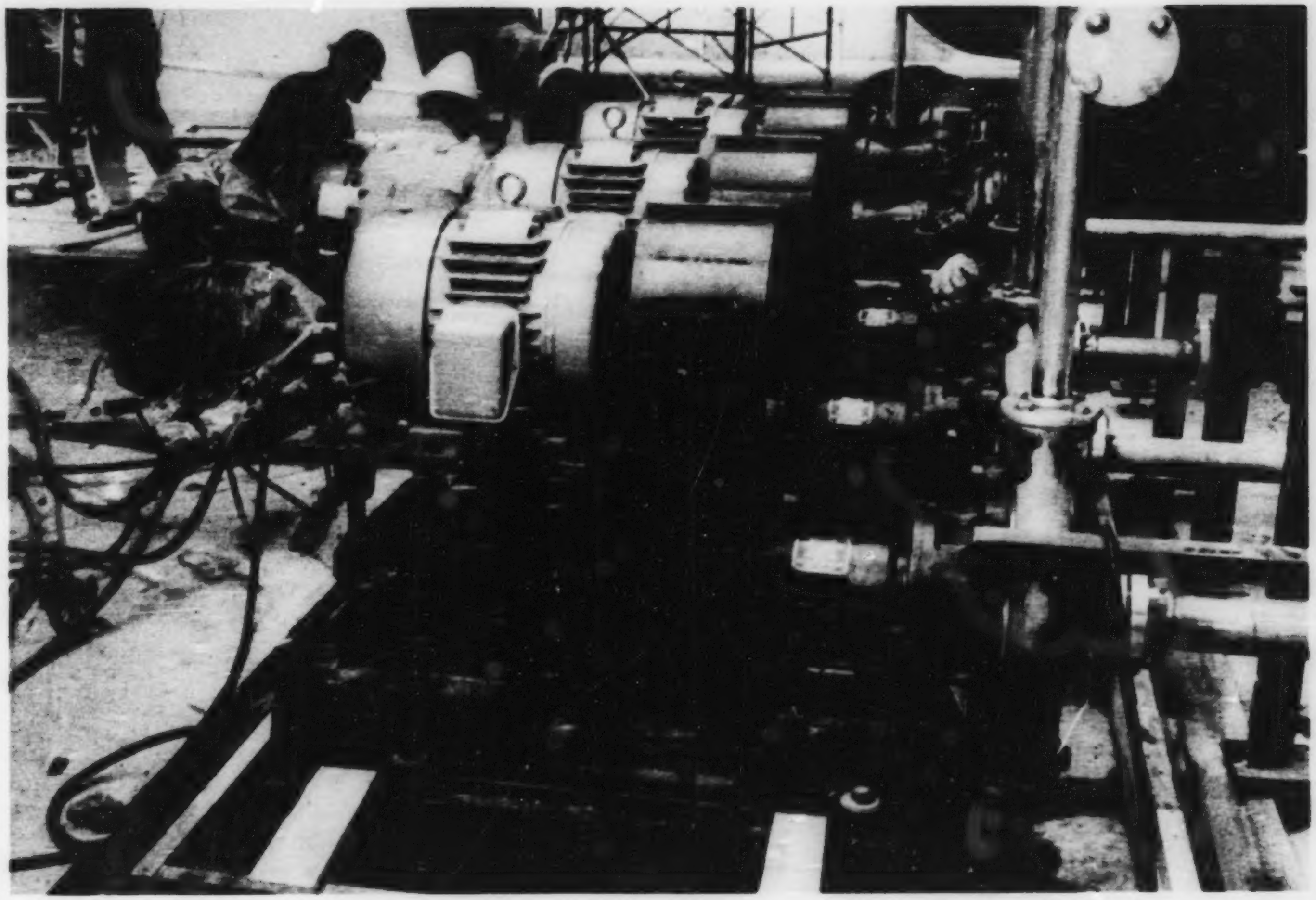

FIGURE 38

Stainless Steel Constant-Speed Centrifugal Pumps (J-3, 4, and 5)

Pumps for Pilot Plant No. 2: Three Allen-Sherman-Hoff pumps coupled with variable-speed drives were used for recirculating liquor to the absorber. These units gave good service except for the failure of the small control motors and mechanical linkages used in the variable-speed drives (same problem as in pilot plant No. 1).

The three Wilfley pumps from the first pilot plant were reused in pilot plant No. 2 for recirculating liquor and supplying forward feed solution to the absorber. One was also used for recirculating evaporator liquor (pH of 2 to 4 and temp. of 220°F). The only problem encountered was some accumulation of crystals around the seal on the pump. Overall, the service of the Wilfley pumps was excellent. Three other types of pumps were used in the plant: (1) Jabsco centrifugal pump for liquid flows to and from filter, (2) Tuthill gear pumps for sulfuric acid and absorber product bleedoff, and (3) Yarway metering pump for sulfuric acid. The Jabsco pumps were air powered and easily portable; overall performance was good. The Tuthill pumps performed well in the acid pumping service, but the fly ash in the product liquor caused scoring of the impeller shaft causing leaks. The Yarway metering pump was not used enough to be evaluated.

Piping for Pilot Plant No. 1: Rubber hoses were used in most of the liquor handling service. These hoses (Fig. 39) gave a maximum of operating flexibility and were trouble free. The connectors for the hoses were Kam-Loc fittings (Fig. 40), a type of quick-connect fitting. This fitting was extremely useful in the pilot-plant work. Cast iron fittings were subject to corrosion but lasted several months before requiring replacement. Stainless steel fittings gave excellent service but were expensive. Some polypropylene fitting was installed and gave good service but was easily damaged. For a long-term operation, the stainless fittings would be the most desirable to install. All rigid piping used for liquor handling was Type 304 or 316 stainless steel and required no maintenance. Rubber-lined (soft rubber) Hills-McCanna valves were used for both throttling and cutoff. The valves showed no signs of deterioration.

Piping for Pilot Plant No. 2: Stainless steel and/or rubber hose was used for all piping. No serious corrosion problems occurred.

Instruments

Differential Pressure Cells for Gas Flow Measurement: The flow of the flue gas through both pilot-plant systems was sensed with a sharp-edged orifice and a Foxboro differential pressure (d/p) cell arrangement. The electrical signal from the d/p cell, which was recorded in the control room, also activated the controller on the variable-speed blower. Some buildup of solids occurred in the ductwork downstream from the orifice. A cleanout door was installed in the ductwork to permit periodic cleaning. The liquid legs to the d/p cell required frequent attention to maintain the required liquid level. Excess

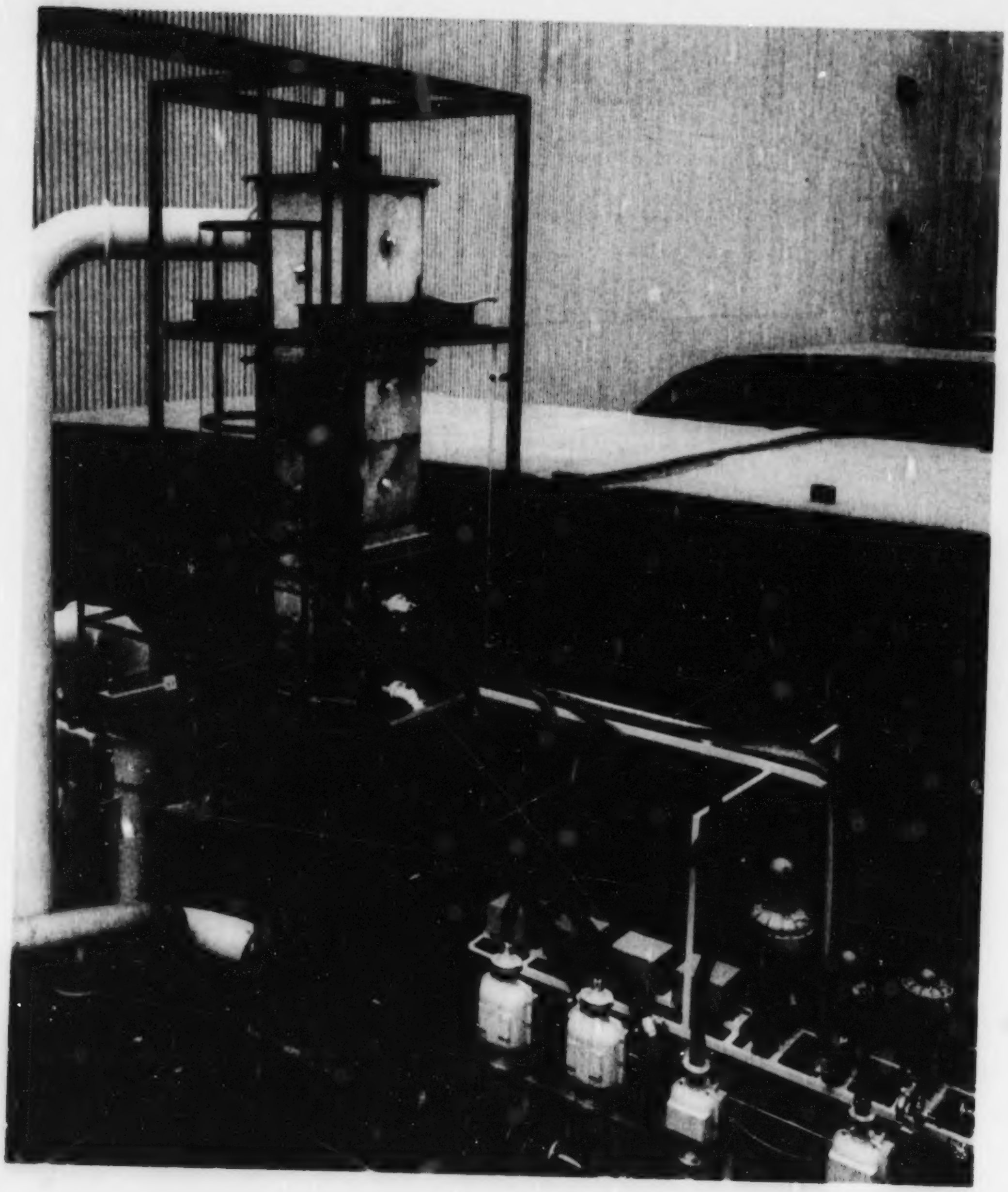

FIGURE 39

Use of Rubber Hose for Operating Flexibility

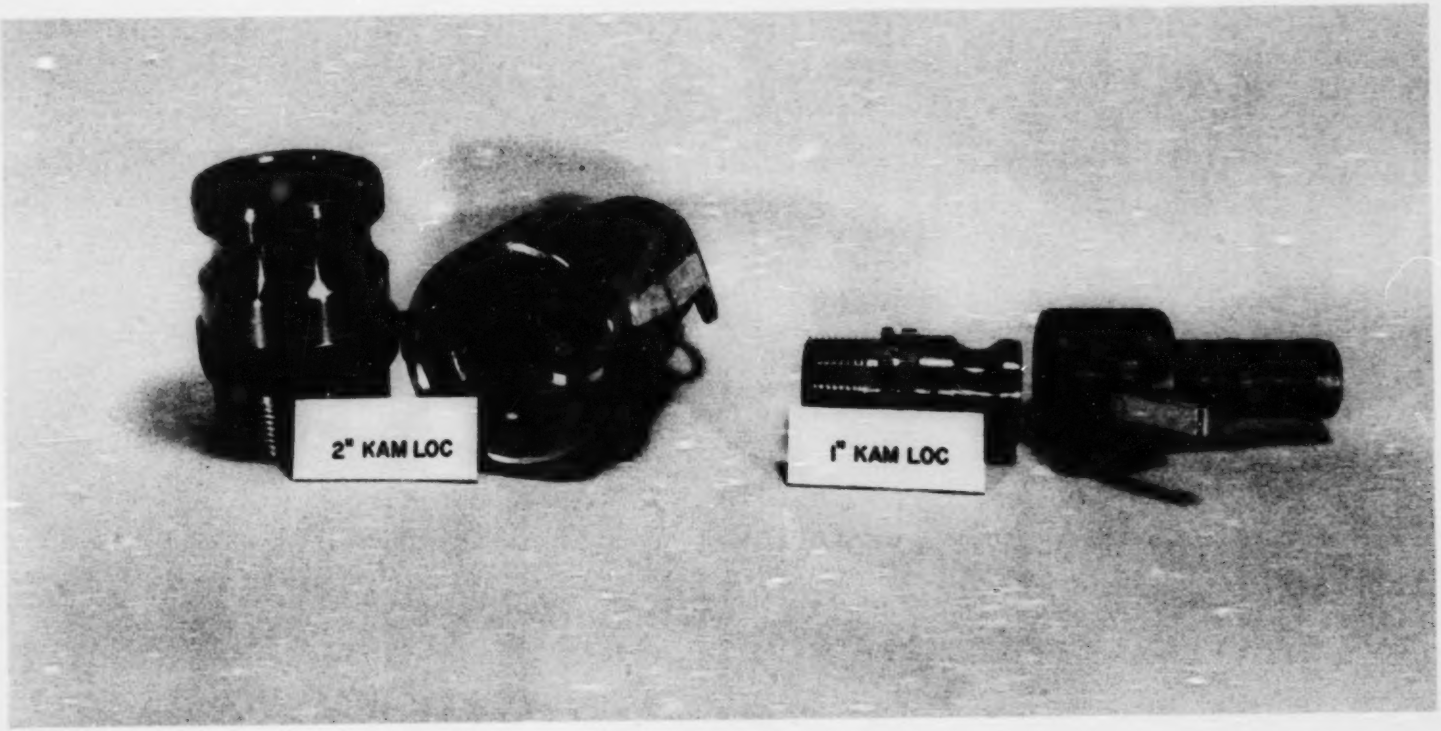

FIGURE 40

Quick-Connect Fittings for Use with Rubber Hose vibrations from the blower system caused mechanical breakages in the line from the taps of the orifices to the d/p cell and in the orifice taps themselves. When maintained properly, the flow-sensing system gave satisfactory service.

Flowmeters for Liquid Flow Measurements for Pilot Plant No. 1: The recirculating liquor flow rate to the individual stages and the product bleedoff rate were measured by Foxboro magnetic flowmeters (Fig. 41). The forward feed flow to the absorber was originally measured using rotameters which were unsatisfactory. The measurements were complicated by changes in the specific gravity and solids content of the feed liquor and by pumping fluctuation in the system. The forward feed liquor flow was regulated with manually operated valves which required frequent operator attention. A transmitting rotameter coupled with an integrator was also used for measuring the forward feed flow rate. This arrangement still did not prove satisfactory. Magnetic flowmeters coupled with automatic flow control valves were then installed and gave good flow control. The forward feed magnetic flowmeters along with the product flowmeter were coupled with flow integrators for detailed accounting of the flows.

Process Recorders and Controllers for Pilot Plant Nos. 1 and 2: Electronic flow recording and controlling instruments manufactured by the Foxboro Company were used in both pilot plants. The instruments were mounted in shelf units installed in the control board (Fig. 42). The shelf units contained wiring terminal boards to which the instrument and the field-mounted flowmeters were connected. The electronic instruments were reliable and required no maintenance over a 3-year period. The data recorded on the strip chart were easily read and provided quick access to past operating conditions. The 12-point temperature recorders, also from Foxboro, were satisfactory. The only maintenance required was an occasional cleaning of the slidewires. Each motor had both a board-mounted and field-mounted control station. No problems were encountered with the Cutler-hammer magnetic starters used throughout the plant. Ammeters were used on all major motors as a check of the loading.

Gas Analyzers for Pilot Plant No. 1: The sulfur dioxide in the gas stream was analyzed with a DuPont split-beam ultraviolet analyzer (Fig. 43). This analyzer was originally equipped with an automatic sampling system which failed to operate properly. The sampling system automatically sequenced through six sampling stations. The solenoid-operated valves operated improperly and leaked, causing serious errors. These valves and all the automatic switches were bypassed and switching from one sample point to another was done manually. The readout from the analyzer was periodically checked by wet-chemical methods. The main problems encountered with the analyzer were (1) the windows inside the measuring tube became dirty and required cleaning, (2) broken wires and loose connections were encountered, and (3) there were possibilities for air leaks throughout the

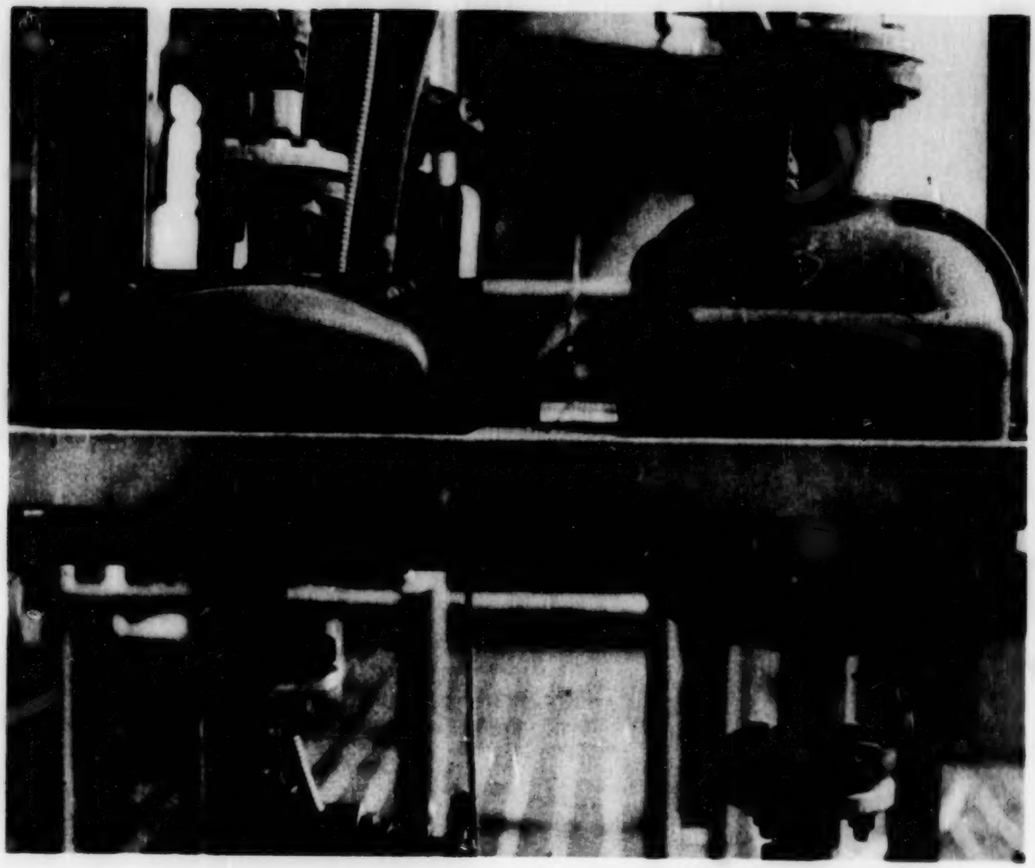

FIGURE 41

Foxboro Magnetic Flowmeters

for Liquid Flow Measurements

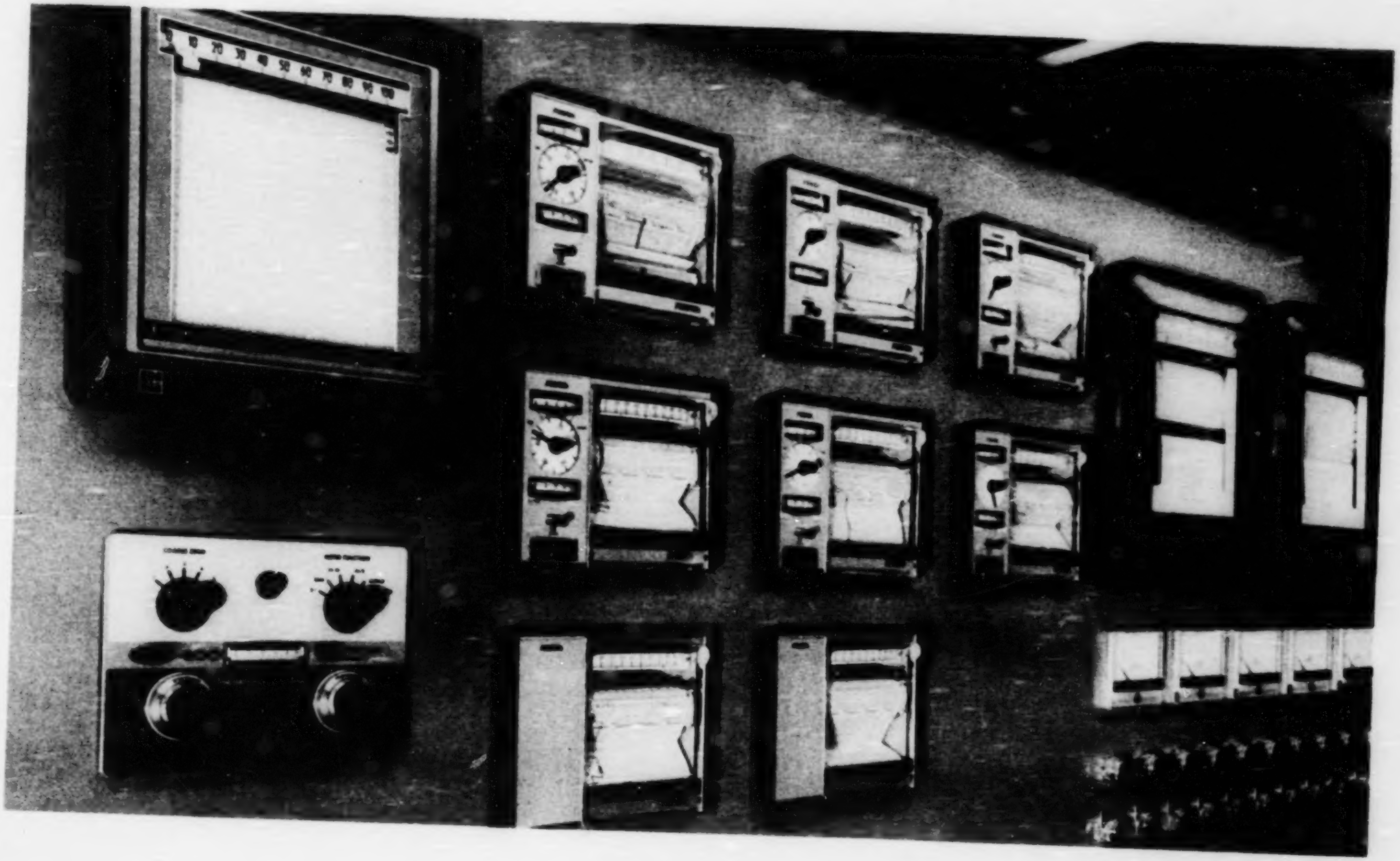

FIGURE 42

Control Board for Pilot Plant

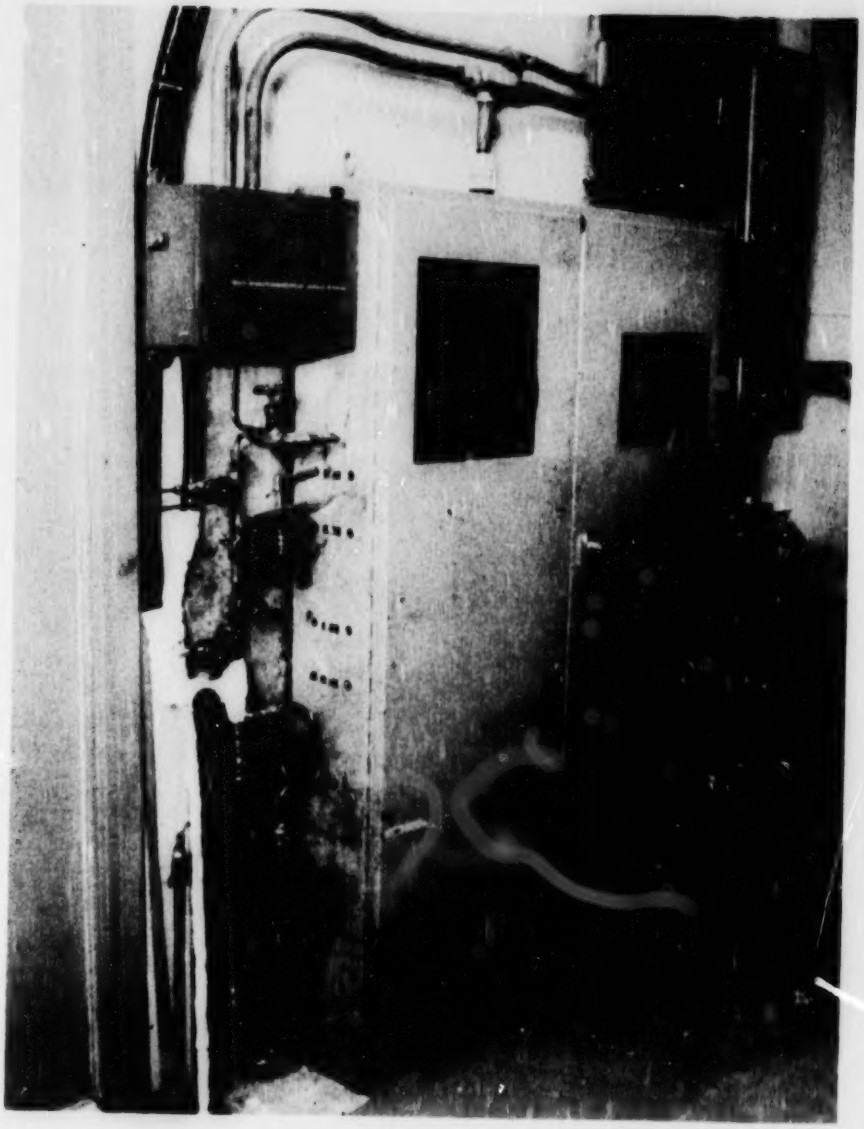

FIGURE 43

Ultraviolet Analyzer for Measuring

Sulfur Dioxide in Flue Gas

instrument and sample lines. A frequent check for leaks was required. The original sample lines were steam-traced, 1/4-inch stainless steel tubing. Ruptures and leaks in the sample lines occurred frequently. Chloride-stress corrosion along with vibration stress from the blower system probably caused the tubing failure.

A commercial sampling line arrangement (Dekoron tubing) was tested and proved satisfactory. This sampling bundle consisted of Teflon tubing with a steam tracer and insulation in a 1-inch-diameter PVC tube.

Gas Analyzers for Pilot Plant No. 2: A DuPont 460 analyzer was used to monitor SO_2 in pilot plant No. 2. The analyzer was equipped with an automatic zero sequence, but was bypassed and the instrument zeroed manually. Sample stations were also manually selected. A glass wool filter (for particulate removal) was added to the sample line just before the analyzer. This reduced the downtime caused by dirty cell windows. The system as a whole gave good results.

The opacity of the plume leaving the absorber was measured in Ringlemann numbers with a Photomation Smoke Monitor. This instrument uses a photocell to measure light transmitted from a single source through the plume. The readings agreed with observation by trained visual emission observers. The lens faces required frequent cleaning but overall operation was good.

Dekoron tubing was used for all gas sampling lines.

Steam Regulator for Pilot Plant No. 1: Steam at a pressure of about 350 psig was obtained from the power plant through a 1-inch line. This line was too small to deliver the quantity of steam needed for proper operation of the soot blowers. At the pilot plant, the pressure was reduced to 30 psig for steam tracing. The Fischer steam regulator originally installed broke and froze. A replacement was ordered but did not arrive until near the end of the test program. In the absence of a regulator, the steam pressure was reduced by a manually operated valve. This gave very poor control.

Steam Regulator for Pilot Plant No. 2: The steam used in the second pilot plant was mostly low pressure (30 psig) for steam tracings and an evaporation coil. A fischer steam regulator was used to reduce the pressure from 350 psig. There were few problems with this system.

APPENDIX C - CONDENSED DATA FROM PILOT-PLANT RUNS

AMMONIA ABSORPTION PILOT PLANT TEST NO.HST-1 ,DEC 23, 1970

	SAMPLE PERIOD				
	A	B	C	D	MEAN
GAS TO SCRUBBER					
FLOW RATE, CFM AT 120 F	2808.	2756.	2756.	2756.	2769.
TEMPERATURE, F	210.0	210.0	210.0	210.0	210.0
DUST, GRAINS/CU.FT.,DRY BASIS	2.4300	2.4300	2.4300	2.4300	2.4300
SO2, PPM	2800.	2800.	2800.	3040.	2860.
EXCESS AIR, PERCENT OXYGEN	4.	6.	5.	5.	5.
GAS FROM SCRUBBER					
G-1 ELEMENT					
SO2, PPM	100.	105.	105.	100.	103.
G-2 ELEMENT					
SO2, PPM	30.	60.	60.	30.	45.
G-3 ELEMENT					
SO2, PPM	50.	60.	50.	60.	55.
NH3, PPM	-	-	-	-	-
DUST, GRAINS/CU.FT.	.0152	.0152	.0154	.0154	.0153
TEMPERATURE, F					
WET-BULB	110.	110.	110.	110.	110.
DRY-BULB	112.	112.	112.	112.	112.
PERCENT SO2 REMOVAL	98.21	97.86	98.21	98.03	98.08
MAKEUP LIQUOR TO SCRUBBER					
SULFITE SULFUR, G/L	47.1	41.2	36.8	40.4	41.4
BISULFITE SULFUR, G/L	29.8	32.4	33.8	32.5	32.1
SULFATE SULFUR, G/L	15.3	17.6	18.6	16.3	17.0
PH	6.50	6.40	6.40	6.40	6.43
SPECIFIC GRAVITY	1.142	1.142	1.144	1.144	1.143
FORWARD FEED, GPM	3.0	3.0	3.0	3.0	3.0
PERCENT FORWARD FLOW TO G-3	12.	12.	12.	12.	12.
RECIRCULATION RATE, GPM					
G-1	28.	28.	28.	28.	28.
G-2	27.	28.	27.	27.	27.
G-3	27.	27.	27.	27.	27.
RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	35.1	35.1	32.2	32.2	33.7
BISULFATE SULFUR, G/L	46.0	46.0	46.0	46.0	46.0
SULFATE SULFUR, G/L	15.1	15.1	14.0	14.0	14.6
PH	6.10	6.10	6.10	6.10	6.10
SPECIFIC GRAVITY	1.144	1.144	1.142	1.142	1.143
G-2 ELEMENT					
SULFITE SULFUR, G/L	40.9	40.9	35.4	35.4	38.2
BISULFATE SULFUR, G/L	29.2	29.2	29.8	29.8	46.0
SULFATE SULFUR, G/L	10.1	10.1	16.0	16.0	13.1
PH	6.40	6.40	6.40	6.40	6.40
SPECIFIC GRAVITY	1.128	1.128	1.128	1.128	1.128
G-3 ELEMENT					
SULFITE SULFUR, G/L	18.2	18.2	15.9	15.9	17.1
BISULFATE SULFUR, G/L	15.6	15.6	15.6	15.6	15.6
SULFATE SULFUR, G/L	15.3	15.3	12.6	12.6	14.0
PH	6.40	6.40	6.30	6.30	6.35
SPECIFIC GRAVITY	1.068	1.068	1.074	1.074	1.071
RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	25.5	31.3	26.3	23.7	26.7
BISULFATE SULFUR, G/L	94.5	91.2	96.4	97.7	95.0
SULFATE SULFUR, G/L	19.2	17.7	18.5	20.8	19.1
PH	6.00	6.00	5.90	5.90	5.95
SPECIFIC GRAVITY	1.150	1.152	1.146	1.152	1.150
G-2 ELEMENT					
SULFITE SULFUR, G/L	35.8	36.5	30.0	31.1	33.4
BISULFATE SULFUR, G/L	29.2	28.5	29.8	30.5	29.5
SULFATE SULFUR, G/L	17.2	15.2	14.4	25.6	18.1
PH	6.40	6.40	6.40	6.30	6.38
SPECIFIC GRAVITY	1.126	1.128	1.126	1.130	1.128
G-3 ELEMENT					
SULFITE SULFUR, G/L	14.8	18.6	17.5	16.0	16.7
BISULFATE SULFUR, G/L	15.6	15.6	15.6	16.2	15.7
SULFATE SULFUR, G/L	12.7	8.9	14.0	12.9	12.1
PH	6.40	6.40	6.40	6.40	6.40
SPECIFIC GRAVITY	1.074	1.072	1.068	1.074	1.072
PRODUCT LIQUOR FROM SCRUBBER					
SULFITE SULFUR, G/L	27.3	27.3	27.3	27.3	27.3
BISULFITE SULFUR, G/L	46.7	46.7	46.7	46.7	46.7
SULFATE SULFUR, G/L	20.2	20.2	20.2	20.2	20.2
PH	6.10	6.10	6.10	6.10	6.10
SPECIFIC GRAVITY	1.142	1.142	1.142	1.142	1.142
PRODUCT BLEEDOFF, GPM	5.1	5.1	5.1	5.1	5.1

AMMONIA ABSORPTION PILOT PLANT TEST NO.RST-2 ,DEC 23,1978

	SAMPLE PERIOD A	B	C	D	MEAN
GAS TO SCRUBBER					
FLOW RATE, CFM AT 170 F	2704.	2704.	2652.	2652.	2678.
TEMPERATURE, F	180.0	180.0	180.0	180.0	180.0
DUST, GRAINS/CU.FT., DRY BASIS	2.4300	2.4300	2.4300	2.4300	2.4300
SO2, PPM	3200.	3200.	3200.	3200.	3200.
EXCESS AIR, PERCENT OXYGEN	5.	5.	5.	5.	5.
GAS FROM SCRUBBER					
G-1 ELEMENT					
SO2, PPM	640.	720.	680.	720.	690.
G-2 ELEMENT					
SO2, PPM	80.	80.	78.	78.	79.
G-3 ELEMENT					
SO2, PPM	55.	40.	35.	35.	41.
NH3, PPM	-	-	-	-	-
DUST, GRAINS/CU.FT.	0.0152	0.0152	0.0152	0.0152	0.0152
TEMPERATURE, F					
WET-BULB	108.	109.	110.	111.	110.
DRY-BULB	110.	111.	112.	113.	111.
PERCENT SO2 REMOVAL	98.28	98.75	98.91	98.91	98.71
MAKEUP LIQUOR TO SCRUBBER					
SULFITE SULFUR, G/L	36.8	40.4	47.1	41.2	41.4
BISULFITE SULFUR, G/L	33.8	32.5	29.8	32.4	32.1
SULFATE SULFUR, G/L	18.6	16.3	15.3	17.6	17.0
PH	6.40	6.40	6.50	6.40	6.43
SPECIFIC GRAVITY	1.144	1.144	1.142	1.142	1.143
FORWARD FEED, GPM	9.0	9.0	9.0	9.0	9.0
PERCENT FORWARD FLOW TO G-3	6.	6.	6.	6.	6.
RECIRCULATION RATE, GPM					
G-1	28.	28.	28.	28.	28.
G-2	28.	28.	28.	28.	28.
G-3	27.	27.	27.	27.	27.
RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	20.9	20.9	19.3	19.3	20.1
BISULFATE SULFUR, G/L	61.1	61.1	58.5	58.5	59.8
SULFATE SULFUR, G/L	18.2	18.2	18.4	18.4	18.3
PH	5.90	5.90	5.90	5.90	5.90
SPECIFIC GRAVITY	1.150	1.150	1.146	1.146	1.148
G-2 ELEMENT					
SULFITE SULFUR, G/L	33.5	33.5	29.6	29.6	31.6
BISULFATE SULFUR, G/L	36.4	36.4	38.4	38.4	37.4
SULFATE SULFUR, G/L	13.3	13.3	15.2	15.2	14.3
PH	6.30	6.30	6.30	6.30	6.30
SPECIFIC GRAVITY	1.130	1.130	1.130	1.130	1.130
G-3 ELEMENT					
SULFITE SULFUR, G/L	17.3	17.3	19.2	19.2	18.2
BISULFATE SULFUR, G/L	23.4	23.4	24.7	24.7	24.1
SULFATE SULFUR, G/L	14.4	14.4	13.2	13.2	13.8
PH	6.30	6.30	6.30	6.30	6.30
SPECIFIC GRAVITY	1.088	1.088	1.092	1.092	1.090
RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	15.9	16.9	19.9	12.8	16.4
BISULFATE SULFUR, G/L	66.1	67.4	63.7	65.0	65.6
SULFATE SULFUR, G/L	25.2	21.9	15.6	24.4	21.8
PH	5.80	5.80	5.80	5.80	5.80
SPECIFIC GRAVITY	1.152	1.154	1.150	1.150	1.152
G-2 ELEMENT					
SULFITE SULFUR, G/L	28.1	24.9	28.0	24.1	26.3
BISULFATE SULFUR, G/L	35.7	37.0	37.7	39.0	37.4
SULFATE SULFUR, G/L	17.4	20.3	16.5	20.1	18.6
PH	6.30	6.20	6.20	6.20	6.23
SPECIFIC GRAVITY	1.130	1.130	1.132	1.130	1.131
G-3 ELEMENT					
SULFITE SULFUR, G/L	18.4	14.8	16.0	16.6	16.5
BISULFATE SULFUR, G/L	21.4	22.7	24.7	25.4	23.5
SULFATE SULFUR, G/L	15.3	18.6	14.4	16.1	16.1
PH	6.40	6.30	6.20	6.20	6.28
SPECIFIC GRAVITY	1.088	1.088	1.090	1.090	1.089
PRODUCT LIQUOR FROM SCRUBBER					
SULFITE SULFUR, G/L	21.2	21.2	21.2	21.2	21.2
BISULFITE SULFUR, G/L	57.2	57.2	57.2	57.2	57.2
SULFATE SULFUR, G/L	14.8	14.8	14.8	14.8	14.8
PH	5.90	5.90	5.90	5.90	5.90
SPECIFIC GRAVITY	1.148	1.148	1.148	1.148	1.148
PRODUCT BLEEDOFF, GPM	3.3	3.3	3.3	3.3	3.3

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       AMMONIA ABSORPTION PILOT PLANT TEST NO.HST-3   ,1-4-71

                                                           SAMPLE PERIOD
                                               A          B          C          D        MEAN
  GAS TO SCRUBBER
    FLOW RATE, CFM AT 120 F
    TEMPERATURE, F                           2288.      2288.      2288.      2288.      2288.
    DUST, GRAINS/CU.FT.,DRY BASIS            180.0      180.0      180.0      180.0      180.0
    SO2, PPM                                0.2810     0.2810     0.2810     0.2810     0.2810
    EXCESS AIR, PERCENT OXYGEN               3320.      3320.      3320.      3320.      3320.
                                                6.         6.         6.         6.         6.
  GAS FROM SCRUBBER
    G-1 ELEMENT
      SO2, PPM
                                              560.       540.       560.       560.       555.
    G-2 ELEMENT
      SO2, PPM
                                              400.       400.       380.       360.       385.
    G-3 ELEMENT
      SO2, PPM
      NH3, PPM                                 50.        60.        40.        50.        50.
      DUST, GRAINS/CU.FT.                       -          -          -          -          -
      TEMPERATURE, F                        0.0354     0.0354     0.0354     0.0354     0.0354
        WET-BULB
        DRY-BULB                              101.       101.       101.       101.       101.
                                              104.       104.       104.       104.       104.
  PERCENT SO2 REMOVAL
                                             98.49      98.19      98.80      98.49      98.49
  MAKEUP LIQUOR TO SCRUBBER
    SULFITE SULFUR, G/L
    BISULFITE SULFUR, G/L                     68.1       70.1       70.1       72.0       70.1
    SULFATE SULFUR, G/L                       52.7       53.3       53.4       53.1       53.1
    PH                                        20.5       19.9       17.8       16.2       18.6
    SPECIFIC GRAVITY                          5.80       6.10       6.40       6.40       6.18
    FORWARD FEED, GPM                        1.208      1.210      1.210      1.210      1.210
    PERCENT FORWARD FLOW TO G-3                3.0        3.0        3.0        3.0        3.0
                                               12.        12.        12.        12.        12.
  RECIRCULATION RATE, GPM
    G-1
    G-2                                        28.        28.        28.        28.        28.
    G-3                                        27.        27.        27.        27.        27.
                                               27.        26.        27.        27.        27.
  RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS
    G-1 ELEMENT
      SULFITE SULFUR, G/L
      BISULFITE SULFUR, G/L                   56.8       56.8       52.2       52.2       54.5
      SULFATE SULFUR, G/L                     75.4       75.4       78.7       78.7       77.1
      PH                                      11.1       11.1       13.4       13.4       12.2
      SPECIFIC GRAVITY                        6.00       6.00       6.00       6.00       6.00
                                             1.204      1.204      1.208      1.208      1.206
    G-2 ELEMENT
      SULFITE SULFUR, G/L
      BISULFITE SULFUR, G/L                   61.9       61.9       57.1       57.1       59.5
      SULFATE SULFUR, G/L                     52.7       52.7       52.0       52.0       77.1
      PH                                      12.7       12.7       10.1       10.1       11.4
      SPECIFIC GRAVITY                        6.00       6.00       6.10       6.10       6.05
                                             1.190      1.190      1.184      1.184      1.187
    G-3 ELEMENT
      SULFITE SULFUR, G/L
      BISULFITE SULFUR, G/L                   17.9       17.9       18.2       18.2       18.1
      SULFATE SULFUR, G/L                     20.2       20.2       21.5       21.5       20.9
      PH                                      12.0       12.0       13.4       13.4       12.7
      SPECIFIC GRAVITY                        6.00       6.00       5.80       5.80       5.90
                                             1.074      1.074      1.080      1.080      1.077
  RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS
    G-1 ELEMENT
      SULFITE SULFUR, G/L
      BISULFITE SULFUR, G/L                   55.2       46.0       52.7       49.6       50.9
      SULFATE SULFUR, G/L                     81.9       82.6       84.7       87.8       84.3
      PH                                      16.2       23.7       12.9       13.9       16.7
      SPECIFIC GRAVITY                        6.00       5.80       5.95       5.90       5.91
                                             1.214      1.210      1.214      1.214      1.213
    G-2 ELEMENT
      SULFITE SULFUR, G/L
      BISULFITE SULFUR, G/L                   55.1       55.1       60.0       60.0       57.6
      SULFATE SULFUR, G/L                     52.0       52.0       52.7       53.3       52.5
      PH                                      23.2       19.2        9.5       10.0       15.5
      SPECIFIC GRAVITY                        6.00       6.00       6.20       6.25       6.11
                                             1.188      1.190      1.190      1.190      1.190
    G-3 ELEMENT
      SULFITE SULFUR, G/L
      BISULFITE SULFUR, G/L                   18.0       17.1       15.6       19.6       17.6
      SULFATE SULFUR, G/L                     21.5       20.2       20.2       20.8       20.7
      PH                                      13.6       17.8       14.3       11.7       14.4
      SPECIFIC GRAVITY                        5.90       5.90       5.90       6.15       5.96
                                             1.080      1.076      1.074      1.076      1.077
  PRODUCT LIQUOR FROM SCRUBBER
    SULFITE SULFUR, G/L
    BISULFITE SULFUR, G/L                     51.2       51.2       51.2       51.2       51.2
    SULFATE SULFUR, G/L                       78.7       78.7       78.7       78.7       78.7
    PH                                        17.4       17.4       17.4       17.4       17.4
    SPECIFIC GRAVITY                          5.85       5.85       5.85       5.85       5.85
    PRODUCT BLEEDOFF, GPM                    1.210      1.210      1.210      1.210      1.210
                                               5.1        5.1        5.1        5.1        5.1
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AMMONIA ABSORPTION PILOT PLANT TEST NO.MST-4   ,1-4-71


                                                    SAMPLE PERIOD
                                          A         B          C          D         MEAN

GAS TO SCRUBBER
  FLOW RATE, CFM AT 120 F
  TEMPERATURE, F                        2288.      2288.      2288.      2288.      2288.
  DUST, GRAINS/CU.FT.,DRY BASIS         210.0      210.0      210.0      210.0      210.0
  SO2, PPM                             0.2810     0.2810     0.2810     0.2810     0.2810
  EXCESS AIR, PERCENT OXYGEN            3520.      3520.      3520.      3520.      3520.
                                           5.         5.         5.         5.         5.

GAS FROM SCRUBBER
  G-1 ELEMENT
    SO2, PPM
                                         500.       480.       480.       380.       460.
  G-2 ELEMENT
    SO2, PPM
                                         100.        95.        95.        95.        96.
  G-3 ELEMENT
    SO2, PPM
    NH3, PPM                              50.        50.        56.        60.        53.
    DUST, GRAINS/CU.FT.                    -          -          -          -          -
    TEMPERATURE, F                     0.0090     0.0090     0.0090     0.0090     0.0090
      WET-BULB
      DRY-BULB                           103.       103.       103.       103.       103.
                                         103.       103.       104.       103.       103.

PERCENT SO2 REMOVAL                     98.58      98.58      98.58      98.30      98.51

MAKEUP LIQUOR TO SCRUBBER
  SULFITE SULFUR, G/L                    70.1       72.0       68.1       70.1       70.1
  BISULFITE SULFUR, G/L                  53.4       53.1       52.7       53.3       53.1
  SULFATE SULFUR, G/L                    17.8       16.2       20.5       19.9       18.6
  PH                                     6.46       6.40       5.80       6.10       6.17
  SPECIFIC GRAVITY                      1.210      1.210      1.208      1.210      1.210
  FORWARD FEED, GPM                       5.6        5.6        5.5        5.0        5.0
  PERCENT FORWARD FLOW TO G-3              6.         6.         6.         6.         6.

RECIRCULATION RATE, GPM
  G-1                                     28.        28.        28.        28.        28.
  G-2                                     27.        27.        27.        27.        27.
  G-3                                     27.        27.        27.        27.        27.

RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS
  G-1 ELEMENT
    SULFITE SULFUR, G/L                  56.3       56.3       51.4       51.4       53.9
    BISULFATE SULFUR, G/L                67.2       67.2       69.2       69.2       68.2
    SULFATE SULFUR, G/L                  16.8       16.8       18.7       18.7       17.7
    PH                                   6.20       6.20       6.15       6.15       6.18
    SPECIFIC GRAVITY                    1.202      1.202      1.204      1.204      1.203

  G-2 ELEMENT
    SULFITE SULFUR, G/L                  58.4       58.4       56.7       56.7       57.6
    BISULFATE SULFUR, G/L                48.5       48.5       49.8       49.8       49.2
    SULFATE SULFUR, G/L                  20.4       20.4       15.8       15.8       18.1
    PH                                   6.30       6.30       6.30       6.30       6.30
    SPECIFIC GRAVITY                    1.182      1.182      1.184      1.184      1.183

  G-3 ELEMENT
    SULFITE SULFUR, G/L                  12.4       12.4       15.9       15.9       14.2
    BISULFATE SULFUR, G/L                16.8       16.8       18.1       18.1       17.5
    SULFATE SULFUR, G/L                  15.9       15.9       14.1       14.1       15.0
    PH                                   6.20       6.20       6.30       6.30       6.25
    SPECIFIC GRAVITY                    1.066      1.066      1.074      1.074      1.070

RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS
  G-1 ELEMENT
    SULFITE SULFUR, G/L                  52.1       53.3       56.8       56.6       54.7
    BISULFATE SULFUR, G/L                80.2       78.9       71.8       78.2       77.3
    SULFATE SULFUR, G/L                  25.0       19.1       20.7       13.5       19.6
    PH                                   5.90       5.70       6.10       6.00       5.93
    SPECIFIC GRAVITY                    1.216      1.214      1.212      1.212      1.214

  G-2 ELEMENT
    SULFITE SULFUR, G/L                  55.8       54.9       56.1       55.8       55.7
    BISULFATE SULFUR, G/L                49.9       49.8       47.8       49.8       49.3
    SULFATE SULFUR, G/L                  19.6       19.6       17.3       16.7       18.3
    PH                                   6.30       6.10       6.30       6.30       6.25
    SPECIFIC GRAVITY                    1.182      1.184      1.182      1.192      1.185

  G-3 ELEMENT
    SULFITE SULFUR, G/L                  13.0       10.6       12.4       15.9       13.0
    BISULFATE SULFUR, G/L                16.8       17.5       16.8       19.4       17.6
    SULFATE SULFUR, G/L                  12.3       15.0       15.9       14.8       14.5
    PH                                   6.00       6.20       6.20       6.00       6.10
    SPECIFIC GRAVITY                    1.062      1.064      1.066      1.076      1.067

PRODUCT LIQUOR FROM SCRUBBER
  SULFITE SULFUR, G/L                    56.3       56.3       56.3       56.3       56.3
  BISULFITE SULFUR, G/L                  67.2       67.2       67.2       67.2       67.2
  SULFATE SULFUR, G/L                    15.8       15.8       15.8       15.8       15.8
  PH                                     6.20       6.20       6.20       6.20       6.20
  SPECIFIC GRAVITY                      1.204      1.204      1.204      1.204      1.204
  PRODUCT BLEEDOFF, GPM                   3.3        3.3        3.3        3.3        3.3
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AMMONIA ABSORPTION PILOT PLANT TEST NO.MP-1 ,JAN. 7, 1971

	SAMPLE PERIOD				
	A	B	C	D	MEAN
GAS TO SCRUBBER					
FLOW RATE, CFM AT 120 F	2550.	2550.	2550.	2550.	2550.
TEMPERATURE, F	195.0	195.0	195.0	195.0	195.0
DUST, GRAINS/CU.FT., DRY BASIS	1,3800	1,3800	1.3800	1,3800	1,3800
SO2, PPM	3280.	3360.	3360.	3360.	3340.
EXCESS AIR, PERCENT OXYGEN	5.	5.	5.	5.	5.
GAS FROM SCRUBBER					
G-1 ELEMENT					
SO2, PPM	1200.	1200.	1160.	1200.	1190.
G-2 ELEMENT					
SO2, PPM	430.	460.	470.	475.	459.
G-3 ELEMENT					
SO2, PPM	170.	220.	240.	255.	221.
NH3, PPM	-	-	-	-	-
DUST, GRAINS/CU.FT.	0,0038	0,0038	0,0038	0,0038	0,0038
TEMPERATURE, F					
WET-BULB	104.	105.	106.	107.	105.
DRY-BULB	108.	107.	108.	108.	108.
PERCENT SO2 REMOVAL	94,82	93,45	92,86	92,41	93,38
MAKEUP LIQUOR TO SCRUBBER					
SULFITE SULFUR, G/L	50,7	51,1	50,7	51,1	50,9
BISULFITE SULFUR, G/L	59,5	58,8	59,5	58,8	59,2
SULFATE SULFUR, G/L	16,1	28,4	16,1	28,4	22,2
PH	6,10	6,10	6,10	6,10	6,10
SPECIFIC GRAVITY	1,188	1.188	1,188	1,188	1,188
FORWARD FEED, GPM	4,0	4,0	4,0	4,0	4,0
PERCENT FORWARD FLOW TO G-3	9.	9.	9.	9.	9.
RECIRCULATION RATE, GPM					
G-1	30.	30.	30.	30.	30.
G-2	30.	30.	30.	30.	30.
G-3	27.	27.	27.	27.	27.
RECIRCULATING LIQUOR TO **SCRUBBER ELEMENTS**					
G-1 ELEMENT					
SULFITE SULFUR, G/L	30,4	30,4	28,4	28,4	29,4
BISULFATE SULFUR, G/L	95,0	95,0	92,2	92,2	93,6
SULFATE SULFUR, G/L	18,9	18,9	17,7	17,7	18,3
PH	5,70	5,70	5,60	5,60	5,65
SPECIFIC GRAVITY	1,200	1.200	1,198	1,198	1,199
G-2 ELEMENT					
SULFITE SULFUR, G/L	36,4	36,4	33,0	33,0	34,7
BISULFATE SULFUR, G/L	67,2	67,2	67,7	67,7	93,6
SULFATE SULFUR, G/L	16,6	16,6	16,5	16,5	16,6
PH	5,90	5,90	5,80	5,80	5,85
SPECIFIC GRAVITY	1,172	1.172	1,170	1,170	1,171
G-3 ELEMENT					
SULFITE SULFUR, G/L	22,6	22,6	13,0	13,0	17,8
BISULFATE SULFUR, G/L	46,6	46,6	43,8	43,8	45,2
SULFATE SULFUR, G/L	14,0	14,0	17,4	17,4	15,7
PH	5,90	5,90	5,80	5,80	5,85
SPECIFIC GRAVITY	1,120	1.120	1,108	1,108	1,114
RECIRCULATING LIQUOR FROM **SCRUBBER ELEMENTS**					
G-1 ELEMENT					
SULFITE SULFUR, G/L	36,9	29,7	27,8	28,3	30,7
BISULFATE SULFUR, G/L	100,8	101,5	102,8	101,3	101,6
SULFATE SULFUR, G/L	14,6	23,1	17,7	17,7	18,3
PH	6,00	5,60	5,60	5,50	5,68
SPECIFIC GRAVITY	1,206	1.206	1,204	1,202	1,205
G-2 ELEMENT					
SULFITE SULFUR, G/L	39,3	35,1	29,3	28,4	33,0
BISULFATE SULFUR, G/L	67,2	68,5	72,4	69,1	69,3
SULFATE SULFUR, G/L	17,8	16,6	17,5	20,7	18,2
PH	6,00	5,90	5,80	5,90	5,90
SPECIFIC GRAVITY	1,176	1.174	1,172	1,170	1,173
G-3 ELEMENT					
SULFITE SULFUR, G/L	26,0	24,1	20,4	15,2	21,4
BISULFATE SULFUR, G/L	48,5	45,9	45,9	[illegible]	45,9
SULFATE SULFUR, G/L	22,7	14,2	13,9	[illegible]	17,4
PH	6,00	6,00	5,90	5,80	5,93
SPECIFIC GRAVITY	1,134	1.122	1,116	1,112	1,121
PRODUCT LIQUOR FROM SCRUBBER					
SULFITE SULFUR, G/L	28,1	28,1	28,1	28,1	28,1
BISULFITE SULFUR, G/L	93,8	93,8	93,8	93,8	93,8
SULFATE SULFUR, G/L	18,4	18,4	18,4	18,4	18,4
PH	5,60	5,60	5,60	5,60	5,60
SPECIFIC GRAVITY	1,200	1,200	1,200	1,200	1,200
PRODUCT BLEEDOFF, GPM	4,2	4,2	4,2	4,2	4,2

AMMONIA ABSORPTION PILOT PLANT TEST NO.MP-1R ,APRIL 9,1971

			SAMPLE PERIOD		
	A		C	D	MEAN
GAS TO SCRUBBER					
FLOW RATE, CFM AT 120 F	3000.	3000.	3000.	3000.	3000.
TEMPERATURE, F	196.0	195.0	195.0	195.0	195.3
DUST, GRAINS/CU.FT.,DRY BASIS	0.0047	0.0047	0.0047	0.0047	0.0047
SO2, PPM	2640.	2640.	2500.	2500.	2570.
EXCESS AIR, PERCENT OXYGEN	-	-	-	-	-
GAS FROM SCRUBBER					
G-1 ELEMENT					
SO2, PPM	1000.	960.	880.	880.	930.
G-2 ELEMENT					
SO2, PPM	375.	380.	380.	340.	369.
G-3 ELEMENT					
SO2, PPM	240.	240.	240.	250.	243.
NH3, PPM	169.	169.	169.	169.	169.
DUST, GRAINS/CU.FT.	0.1302	0.1302	0.1302	0.1302	0.1302
TEMPERATURE, F					
WET-BULB	100.	100.	100.	100.	100.
DRY-BULB	110.	109.	109.	110.	110.
PERCENT SO2 REMOVAL	90.91	90.91	90.40	90.00	90.55
MAKEUP LIQUOR TO SCRUBBER					
SULFITE SULFUR, G/L	49.7	50.7	51.3	52.6	51.1
BISULFITE SULFUR, G/L	61.4	61.4	60.7	61.4	61.2
SULFATE SULFUR, G/L	9.7	8.7	9.8	6.8	8.7
PH	-	-	-	-	-
SPECIFIC GRAVITY	1.176	1.176	1.176	1.176	1.176
FOWARD FEED, GPM	4.0	4.0	4.0	4.0	4.0
PERCENT FOWARD FLOW TO G-3	9.	9.	9.	9.	9.
RECIRCULATION RATE, GPM					
G-1	30.	30.	30.	30.	30.
G-2	10.	10.	10.	10.	10.
G-3	10.	10.	10.	10.	10.
RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	35.3	37.9	34.7	34.0	35.5
BISULFATE SULFUR, G/L	84.9	84.2	85.5	85.5	85.0
SULFATE SULFUR, G/L	12.5	10.6	11.5	12.2	11.7
PH	-	-	-	-	-
SPECIFIC GRAVITY	1.186	1.186	1.186	1.186	1.186
G-2 ELEMENT					
SULFITE SULFUR, G/L	39.8	39.8	40.2	40.3	40.0
BISULFATE SULFUR, G/L	84.0	84.5	84.6	84.6	85.0
SULFATE SULFUR, G/L	12.0	10.0	9.0	9.9	10.2
PH	-	-	-	-	-
SPECIFIC GRAVITY	1.166	1.164	1.164	1.164	1.164
G-3 ELEMENT					
SULFITE SULFUR, G/L	23.6	23.6	23.6	23.6	23.6
BISULFATE SULFUR, G/L	49.6	49.6	49.6	49.6	49.6
SULFATE SULFUR, G/L	10.6	9.6	8.6	8.6	9.3
PH	-	-	-	-	-
SPECIFIC GRAVITY	1.122	1.120	1.119	1.118	1.120
RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	32.4	33.9	29.8	29.1	31.3
BISULFATE SULFUR, G/L	97.9	97.9	97.9	97.3	97.8
SULFATE SULFUR, G/L	11.4	8.9	12.0	13.3	11.4
PH	-	-	-	-	-
SPECIFIC GRAVITY	1.192	1.192	1.192	1.192	1.192
G-2 ELEMENT					
SULFITE SULFUR, G/L	36.5	35.9	37.9	36.3	36.7
BISULFATE SULFUR, G/L	68.6	68.6	67.9	67.9	68.3
SULFATE SULFUR, G/L	12.7	13.3	11.0	12.6	12.4
PH	-	-	-	-	-
SPECIFIC GRAVITY	1.166	1.166	1.166	1.166	1.166
G-3 ELEMENT					
SULFITE SULFUR, G/L	26.0	23.2	22.9	22.2	23.6
BISULFATE SULFUR, G/L	49.6	50.9	50.9	50.3	50.4
SULFATE SULFUR, G/L	7.4	9.7	10.0	11.3	9.6
PH	-	-	-	-	-
SPECIFIC GRAVITY	1.123	1.122	1.121	1.121	1.122
PRODUCT LIQUOR FROM SCRUBBER					
SULFITE SULFUR, G/L	36.9	35.6	36.3	36.0	36.2
BISULFITE SULFUR, G/L	87.5	88.8	88.8	88.8	88.5
SULFATE SULFUR, G/L	9.3	8.3	7.6	6.9	8.0
PH	-	-	-	-	-
SPECIFIC GRAVITY	1.184	1.184	1.184	1.184	1.184
PRODUCT BLEEDOFF, GPM	4.4	4.4	4.4	4.4	4.4

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AMMONIA ABSORPTION PILOT PLANT TEST NO,RST-5   ,JAN 20,1971

                                                      SAMPLE PERIOD
                                            A          B          C          D         MEAN

GAS TO SCRUBBER
  FLOW RATE, CFM AT 120 F                 2808,      2808,      2808,      2704,      2782,
  TEMPERATURE, F                          180,0      180,0      180,0      181,0      180,2
  DUST, GRAINS/CU.FT.,DRY BASIS          0,4320     0,4320     0,4320     0,4320     0,4320
  SO2, PPM                                2532,      2532,      2532,      2532,      2532,
  EXCESS AIR, PERCENT OXYGEN                 5,         5,         5,         5,         5,

GAS FROM SCRUBBER
  G-1 ELEMENT
    SO2, PPM                               623,       623,       623,       623,       623,

  G-2 ELEMENT
    SO2, PPM                                 -          -          -          -          -

  G-3 ELEMENT
    SO2, PPM                                 -          -          -          -          -
    NH3, PPM                                 -          -          -          -          -
    DUST, GRAINS/CU.FT.                  0,0124     0,0124     0,0124     0,0124     0,0124
    TEMPERATURE, F
      WET-BULB                              96,        97,        96,        96,        96,
      DRY-BULB                              97,        98,        97,        97,        97,

PERCENT SO2 REMOVAL                          -          -          -          -          -

MAKEUP LIQUOR TO SCRUBBER
  SULFITE SULFUR, G/L                      25,4       25,7       27,0       21,1       24,8
  BISULFITE SULFUR, G/L                    53,2       53,2       53,2       53,2       53,2
  SULFATE SULFUR, G/L                      14,6       15,3       13,0       17,9       15,2
  PH                                       6,10       6,10       6,10       6,10       6,10
  SPECIFIC GRAVITY                        1,138      1,138      1,138      1,138      1,138
  FORWARD FEED, GPM                         5,0        5,0        5,0        5,0        5,0
  PERCENT FORWARD FLOW TO G-3               12,        12,        12,        12,        12,

RECIRCULATION RATE, GPM
  G-1                                       18,        18,        18,        27,        20,
  G-2                                       18,        18,        18,        18,        18,
  G-3                                       18,        1-,        18,        18,        18,

RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS
  G-1 ELEMENT
    SULFITE SULFUR, G/L                    16,5       16,3       17,2       15,9       16,5
    BISULFATE SULFUR, G/L                  68,2       66,8       64,9       68,8       67,2
    SULFATE SULFUR, G/L                    13,5       11,1       14,1       12,5       12,8
    PH                                     5,70       5,70       5,70       5,70       5,70
    SPECIFIC GRAVITY                      1,136      1.138      1,136      1.138      1,137

  G-2 ELEMENT
    SULFITE SULFUR, G/L                    14,5       15,8       15,2       18,1       15,9
    BISULFATE SULFUR, G/L                  65,5       65,5       66,2       59,1       67,2
    SULFATE SULFUR, G/L                    13,2       10,9       14,8       13,0       13,0
    PH                                     5,70       5,70       5,70       5,70       5,70
    SPECIFIC GRAVITY                      1,132      1.132      1,134      1.130      1,132

  G-3 ELEMENT
    SULFITE SULFUR, G/L                     7,9        7,9        7,5       10,7        8,5
    BISULFATE SULFUR, G/L                  52,6       52,6       53,2       48,7       51,8
    SULFATE SULFUR, G/L                     9,6        9,6       11,5       10,7       10,4
    PH                                     5,50       5,50       5,50       5,70       5,55
    SPECIFIC GRAVITY                      1,100      1.102      1,102      1.100      1,101

RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS
  G-1 ELEMENT
    SULFITE SULFUR, G/L                    17,4       14,5       16,9       13,0       15,5
    BISULFATE SULFUR, G/L                 113,8      114,4      104,9       77,2      102,5
    SULFATE SULFUR, G/L                    14,1       17,4       16,9       12,0       15,1
    PH                                     5,40       5,40       5,50       5,60       5,48
    SPECIFIC GRAVITY                      1,198      1.198      1,192      1.146      1,183

  G-2 ELEMENT
    SULFITE SULFUR, G/L                    13,2       12,9       14,4       18,3       14,7
    BISULFATE SULFUR, G/L                  71,1       69,8       68,2       59,1       67,1
    SULFATE SULFUR, G/L                     4,9       14,5       12,6       12,8       11,2
    PH                                     5,60       5,60       5,70       5,70       5,65
    SPECIFIC GRAVITY                      1,138      1.134      1,134      1.130      1,134

  G-3 ELEMENT
    SULFITE SULFUR, G/L                     9,3        0,6        6,4        8,9        6,3
    BISULFATE SULFUR, G/L                  54,3       54,3       53,9       50,0       53,1
    SULFATE SULFUR, G/L                    10,6       20,3        7,6       12,2       12,7
    PH                                     5,50       5,50       5,70       5,60       5,58
    SPECIFIC GRAVITY                      1,102      1.102      1,102      1.100      1,102

 PRODUCT LIQUOR FROM SCRUBBER
  SULFITE SULFUR, G/L                      15,2       16,2       18,2       16,5       16,5
  BISULFITE SULFUR, G/L                    68,2       67,5       66,8       69,5       68,0
  SULFATE SULFUR, G/L                      14,0       12,5       11,2       11,2       12,4
  PH                                       5,70       5,70       5,70       5,70       5,70
  SPECIFIC GRAVITY                        1,140      1.136      1,137      1.140      1,139
  PRODUCT BLEEDOFF, GPM                     6,0        6,0        6,0        6,0        6,0
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AMMONIA ABSORPTION PILOT PLANT TEST NO.AST-5R ,3-31-71

	SAMPLE PERIOD A	B	C	D	MEAN
GAS TO SCRUBBER					
FLOW RATE, CFM AT 120 F	2900.	2900.	2900.	2900.	2900.
TEMPERATURE, F	180.0	180.0	180.0	180.0	180.0
DUST, GRAINS/CU.FT..DRY BASIS	0.3786	0.3786	0.3786	0.3786	0.3786
SO2, PPM	2800.	2800.	2580.	2580.	2690.
EXCESS AIR, PERCENT OXYGEN	4.	4.	4.	4.	4.
GAS FROM SCRUBBER					
G-1 ELEMENT					
SO2, PPM	1160.	1160.	1040.	1040.	1100.
G-2 ELEMENT					
SO2, PPM	450.	440.	420.	410.	430.
G-3 ELEMENT					
SO2, PPM	300.	300.	270.	270.	285.
NH3, PPM	471.	471.	471.	471.	471.
DUST, GRAINS/CU.FT.	-	-	-	-	-
TEMPERATURE, F					
WET-BULB	110.	109.	109.	109.	109.
DRY-BULB	110.	109.	110.	110.	110.
PERCENT SO2 REMOVAL	89.29	89.29	89.53	89.53	89.41
MAKEUP LIQUOR TO SCRUBBER					
SULFITE SULFUR, G/L	28.9	26.9	29.2	29.2	28.5
BISULFITE SULFUR, G/L	44.4	43.7	43.7	43.7	43.9
SULFATE SULFUR, G/L	5.6	8.2	5.9	5.9	6.4
PH	-	-	-	-	-
SPECIFIC GRAVITY	1.144	1.146	1.146	1.144	1.145
FORWARD FEED, GPM	5.0	5.0	5.0	5.0	5.0
PERCENT FORWARD FLOW TO G-3	12.	12.	12.	12.	12.
RECIRCULATION RATE, GPM					
G-1	30.	30.	30.	30.	30.
G-2	18.	18.	18.	18.	18.
G-3	18.	18.	18.	18.	18.
RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	30.0	27.7	26.4	24.3	27.1
BISULFATE SULFUR, G/L	75.7	75.1	73.1	73.8	74.4
SULFATE SULFUR, G/L	8.1	9.0	11.3	12.7	10.3
PH	-	-	-	-	-
SPECIFIC GRAVITY	1.160	1.156	1.158	1.154	1.157
G-2 ELEMENT					
SULFITE SULFUR, G/L	30.7	35.6	32.9	31.3	32.6
BISULFATE SULFUR, G/L	58.1	52.2	56.8	57.5	74.4
SULFATE SULFUR, G/L	10.0	9.0	4.0	6.0	7.3
PH	-	-	-	-	-
SPECIFIC GRAVITY	1.142	1.140	1.138	1.138	1.140
G-3 ELEMENT					
SULFITE SULFUR, G/L	22.9	24.1	23.5	14.8	21.3
BISULFATE SULFUR, G/L	51.6	49.6	49.0	39.8	47.5
SULFATE SULFUR, G/L	6.4	5.1	3.4	6.2	5.3
PH	-	-	-	-	-
SPECIFIC GRAVITY	1.120	1.114	1.112	1.110	1.114
RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	26.6	24.0	25.3	24.6	25.1
BISULFATE SULFUR, G/L	84.9	84.2	82.9	82.3	83.6
SULFATE SULFUR, G/L	8.3	8.6	9.6	8.9	8.8
PH	-	-	-	-	-
SPECIFIC GRAVITY	1.172	1.166	1.162	1.160	1.165
G-2 ELEMENT					
SULFITE SULFUR, G/L	25.2	26.1	26.4	27.4	26.3
BISULFATE SULFUR, G/L	63.3	62.0	61.4	61.4	62.0
SULFATE SULFUR, G/L	11.3	10.7	10.0	8.0	10.0
PH	-	-	-	-	-
SPECIFIC GRAVITY	1.140	1.140	1.140	1.140	1.140
G-3 ELEMENT					
SULFITE SULFUR, G/L	21.6	19.9	17.3	17.3	19.0
BISULFATE SULFUR, G/L	53.5	51.8	51.6	50.9	51.9
SULFATE SULFUR, G/L	4.7	7.3	7.9	8.6	7.1
PH	-	-	-	-	-
SPECIFIC GRAVITY	1.118	1.118	1.110	1.110	1.114
PRODUCT LIQUOR FROM SCRUBBER					
SULFITE SULFUR, G/L	18.8	22.3	24.3	24.3	22.4
BISULFITE SULFUR, G/L	80.9	75.7	73.8	73.8	76.1
SULFATE SULFUR, G/L	15.1	13.7	11.7	12.7	13.3
PH	-	-	-	-	-
SPECIFIC GRAVITY	1.160	1.158	1.156	1.154	1.157
PRODUCT BLEEDOFF, GPM	5.4	5.4	5.4	5.4	5.4

AMMONIA ABSORPTION PILOT PLANT TEST NO,RST-6 ,JAN 26, 1971

	SAMPLE PERIOD				
	A	B	C	D	MEAN
GAS TO SCRUBBER					
FLOW RATE, CFM AT 120 F	2704.	2704.	2704.	2704.	2704.
TEMPERATURE, F	206,0	208,0	209,0	210,0	208,2
DUST, GRAINS/CU,FT.,DRY BASIS	0,4320	0,4320	0,4320	0,4320	0,4320
SO2, PPM	2532.	2532.	2532.	2532.	2532.
EXCESS AIR, PERCENT OXYGEN	8.	7.	6.	6.	7.
GAS FROM SCRUBBER					
G-1 ELEMENT					
SO2, PPM	-	-	-	-	-
G-2 ELEMENT					
SO2, PPM	-	-	-	-	-
G-3 ELEMENT					
SO2, PPM	460.	460.	460.	460.	460.
NH3, PPM	-	-	-	-	-
DUST, GRAINS/CU,FT.	0,0106	0,0106	0,0106	0,0106	0,0106
TEMPERATURE, F					
WET-BULB	99.	99.	99.	99.	99.
DRY-BULB	100.	100.	100.	100.	100.
PERCENT SO2 REMOVAL	81,83	81,83	81,83	81,83	81,83
MAKEUP LIQUOR TO SCRUBBER					
SULFITE SULFUR, G/L	27,4	27,4	27,4	28,7	27,7
BISULFITE SULFUR, G/L	92,6	93,2	93,3	92,6	92,9
SULFATE SULFUR, G/L	12,2	11,0	12,3	10,9	11,6
PH	6,10	6,10	6,10	6,10	6,10
SPECIFIC GRAVITY	1,130	1,130	1,130	1,130	1,130
FOWARD FEED, GPM	3,0	3,0	3,0	3,0	3,0
PERCENT FOWARD FLOW TO G-3	6.	6.	6.	6.	6.
RECIRCULATION RATE, GPM					
G-1	27.	27.	27.	27.	27.
G-2	18.	18.	18.	18.	18.
G-3	18.	18.	18.	18.	18.
RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	12,5	10,2	10,2	12,9	11,5
BISULFATE SULFUR, G/L	70,1	71,4	71,4	70,7	70,9
SULFATE SULFUR, G/L	13,4	13,4	13,6	8,6	12,2
PH	5,60	5,60	5,60	5,60	5,60
SPECIFIC GRAVITY	1,134	1,132	1,136	1,134	1,134
G-2 ELEMENT					
SULFITE SULFUR, G/L	13,9	14,9	14,6	15,3	14,7
BISULFATE SULFUR, G/L	93,9	95,2	94,5	94,5	70,9
SULFATE SULFUR, G/L	13,2	10,9	12,1	10,4	11,7
PH	5,70	5,70	5,70	5,80	5,73
SPECIFIC GRAVITY	1,120	1,120	1,110	1,116	1,118
G-3 ELEMENT					
SULFITE SULFUR, G/L	1,6	2,5	2,9	3,3	2,6
BISULFATE SULFUR, G/L	32,5	32,5	30,5	30,5	31,5
SULFATE SULFUR, G/L	9,9	8,0	8,7	6,3	8,2
PH	5,40	5,40	5,40	5,40	5,40
SPECIFIC GRAVITY	1,062	1,068	1,060	1,050	1,060
RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	12,1	11,0	8,9	8,6	10,1
BISULFATE SULFUR, G/L	77,2	76,6	78,6	77,9	77,6
SULFATE SULFUR, G/L	14,9	11,6	13,7	12,7	13,2
PH	5,50	5,50	5,40	5,40	5,45
SPECIFIC GRAVITY	1,144	1,142	1,142	1,140	1,142
G-2 ELEMENT					
SULFITE SULFUR, G/L	13,0	14,3	10,7	12,7	12,7
BISULFATE SULFUR, G/L	56,4	55,8	57,1	56,4	56,4
SULFATE SULFUR, G/L	12,8	11,1	12,4	12,1	12,1
PH	5,70	5,70	5,70	5,70	5,70
SPECIFIC GRAVITY	1,120	1,120	1,118	1,118	1,119
G-3 ELEMENT					
SULFITE SULFUR, G/L	3,2	-1,0	1,5	-1,7	0,5
BISULFATE SULFUR, G/L	33,1	32,5	31,8	31,1	32,1
SULFATE SULFUR, G/L	9,8	13,6	8,8	12,7	11,2
PH	5,40	5,40	5,40	5,40	5,40
SPECIFIC GRAVITY	1,064	1,062	1,060	1,060	1,062
PRODUCT LIQUOR FROM SCRUBBER					
SULFITE SULFUR, G/L	10,3	9,9	11,5	13,1	11,2
BISULFITE SULFUR, G/L	70,7	71,4	71,4	70,1	70,9
SULFATE SULFUR, G/L	16,2	13,9	12,3	11,0	13,4
PH	5,60	5,60	5,60	5,60	5,60
SPECIFIC GRAVITY	1,136	1,136	1,136	1,136	1,136
PRODUCT BLEEDOFF, GPM	3,5	3,5	3,5	3,5	3,5

AMMONIA ABSORPTION PILOT PLANT TEST NO.RST-6B ,3-31-71

	SAMPLE PERIOD				
	A	B	C	D	MEAN
GAS TO SCRUBBER					
FLOW RATE, CFM AT 120 F	2900.	2900.	2900.	2900.	2900.
TEMPERATURE, F	210.0	210.0	210.0	200.0	207.5
DUST, GRAINS/CU.FT.,DRY BASIS	0.5942	0.5942	0.5942	0.5942	0.5942
SO2, PPM	2640.	2640.	2720.	2720.	2680.
EXCESS AIR, PERCENT OXYGEN	4.	4.	4.	4.	4.
GAS FROM SCRUBBER					
G-1 ELEMENT					
SO2, PPM	1520.	1520.	1520.	1520.	1520.
G-2 ELEMENT					
SO2, PPM	650.	650.	650.	690.	660.
G-3 ELEMENT					
SO2, PPM	525.	520.	530.	560.	534.
NH3, PPM	421.	421.	421.	421.	421.
DUST, GRAINS/CU.FT.	-	-	-	-	-
TEMPERATURE, F					
WET-BULB	109.	110.	110.	109.	110.
DRY-BULB	110.	111.	111.	110.	111.
PERCENT SO2 REMOVAL	80.11	80.30	80.51	79.41	80.09
MAKEUP LIQUOR TO SCRUBBER					
SULFITE SULFUR, G/L	35.3	34.6	35.6	33.5	34.8
BISULFITE SULFUR, G/L	94.8	95.5	95.5	94.2	95.0
SULFATE SULFUR, G/L	8.7	8.7	7.7	11.1	9.0
PH	-	-	-	-	-
SPECIFIC GRAVITY	1.147	1.147	1.147	1.148	1.147
FORWARD FEED, GPM	3.0	3.0	3.0	3.0	3.0
PERCENT FORWARD FLOW TO G-3	6.	6.	6.	6.	6.
RECIRCULATION RATE, GPM					
G-1	30.	30.	30.	30.	30.
G-2	10.	10.	10.	10.	10.
G-3	10.	10.	10.	10.	10.
RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	21.9	22.8	21.6	21.8	22.1
BISULFATE SULFUR, G/L	87.5	84.9	83.6	83.6	84.9
SULFATE SULFUR, G/L	10.4	9.1	10.4	9.4	9.8
PH	-	-	-	-	-
SPECIFIC GRAVITY	1.166	1.164	1.162	1.162	1.164
G-2 ELEMENT					
SULFITE SULFUR, G/L	27.4	26.7	25.1	21.6	25.2
BISULFATE SULFUR, G/L	58.8	58.8	60.1	62.0	59.9
SULFATE SULFUR, G/L	8.6	8.3	7.6	7.2	7.9
PH	-	-	-	-	-
SPECIFIC GRAVITY	1.135	1.136	1.134	1.132	1.134
G-3 ELEMENT					
SULFITE SULFUR, G/L	8.5	6.8	7.2	7.5	7.5
BISULFATE SULFUR, G/L	45.7	44.4	42.4	40.5	43.3
SULFATE SULFUR, G/L	6.7	4.7	5.3	5.9	5.6
PH	-	-	-	-	-
SPECIFIC GRAVITY	1.088	1.083	1.080	1.078	1.082
RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	17.1	19.1	16.1	17.5	17.5
BISULFATE SULFUR, G/L	95.3	94.0	93.4	92.7	93.9
SULFATE SULFUR, G/L	11.4	10.7	11.3	10.6	11.0
PH	-	-	-	-	-
SPECIFIC GRAVITY	1.172	1.172	1.170	1.168	1.171
G-2 ELEMENT					
SULFITE SULFUR, G/L	21.4	22.4	20.9	19.6	21.1
BISULFATE SULFUR, G/L	65.9	64.6	65.9	65.9	65.6
SULFATE SULFUR, G/L	9.5	9.8	7.0	6.3	8.1
PH	-	-	-	-	-
SPECIFIC GRAVITY	1.138	1.138	1.136	1.135	1.137
G-3 ELEMENT					
SULFITE SULFUR, G/L	8.5	8.2	7.5	7.2	7.9
BISULFATE SULFUR, G/L	47.0	45.0	43.7	42.4	44.5
SULFATE SULFUR, G/L	5.4	5.7	5.7	4.3	5.3
PH	-	-	-	-	-
SPECIFIC GRAVITY	1.090	1.088	1.082	1.080	1.085
PRODUCT LIQUOR FROM SCRUBBER					
SULFITE SULFUR, G/L	19.2	20.5	18.6	17.6	19.0
BISULFITE SULFUR, G/L	88.8	87.5	84.9	84.9	86.5
SULFATE SULFUR, G/L	10.8	7.8	10.3	11.3	10.0
PH	-	-	-	-	-
SPECIFIC GRAVITY	1.166	1.164	1.160	1.160	1.163
PRODUCT BLEEDOFF, GPM	3.3	3.3	3.3	3.3	3.3

AMMONIA ABSORPTION PILOT PLANT TEST NO.RBT-7 ,2-1-71

	SAMPLE PERIOD A	B	C	D	MEAN
GAS TO SCRUBBER					
FLOW RATE, CFM AT 120 F	2964.	2964.	2964.	2964.	2964.
TEMPERATURE, F	100.0	100.0	100.0	101.0	100.2
DUST, GRAINS/CU.FT.,DRY BASIS	3.7600	3.7600	3.7600	3.7600	3.7600
SO2, PPM	2640.	2650.	2660.	2660.	2653.
EXCESS AIR, PERCENT OXYGEN	5.	5.	8.	7.	6.
GAS FROM SCRUBBER					
G-1 ELEMENT					
SO2, PPM	1680.	1760.	1680.	1700.	1709.
G-2 ELEMENT					
SO2, PPM	720.	680.	720.	710.	707.
G-3 ELEMENT					
SO2, PPM	530.	530.	520.	520.	525.
NH3, PPM	-	-	-	-	-
DUST, GRAINS/CU.FT.	0.0022	0.0022	0.0022	0.0022	0.0022
TEMPERATURE, F					
WET-BULB	92.	91.	91.	91.	91.
DRY-BULB	94.	93.	94.	94.	94.
PERCENT SO2 REMOVAL	79.92	80.00	80.45	80.45	80.21
MAKEUP LIQUOR TO SCRUBBER					
SULFITE SULFUR, G/L	31.0	31.0	31.0	31.0	31.0
BISULFITE SULFUR, G/L	49.3	49.3	49.3	49.3	49.3
SULFATE SULFUR, G/L	11.7	11.7	11.7	10.7	11.4
PH	6.20	6.20	6.20	6.20	6.20
SPECIFIC GRAVITY	1.140	1.140	1.140	1.140	1.140
FOWARD FEED, GPM	3.0	3.0	3.0	3.0	3.0
PERCENT FOWARD FLOW TO G-3	12.	12.	12.	12.	12.
RECIRCULATION RATE, GPM					
G-1	24.	24.	24.	24.	24.
G-2	10.	10.	10.	10.	10.
G-3	10.	10.	10.	10.	10.
RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	11.0	10.0	10.6	10.4	10.5
BISULFATE SULFUR, G/L	72.0	72.7	74.0	74.6	73.3
SULFATE SULFUR, G/L	11.8	12.1	14.2	12.8	12.7
PH	5.60	5.90	5.90	5.90	5.93
SPECIFIC GRAVITY	1.136	1.140	1.142	1.142	1.140
G-2 ELEMENT					
SULFITE SULFUR, G/L	12.2	15.0	15.0	16.0	14.6
BISULFATE SULFUR, G/L	58.4	59.1	59.1	59.1	73.3
SULFATE SULFUR, G/L	13.2	10.7	11.7	11.0	11.6
PH	5.80	5.80	5.80	5.80	5.80
SPECIFIC GRAVITY	1.122	1.124	1.126	1.126	1.125
G-3 ELEMENT					
SULFITE SULFUR, G/L	4.2	7.2	7.5	2.3	5.3
BISULFATE SULFUR, G/L	43.5	44.1	44.8	45.4	44.5
SULFATE SULFUR, G/L	10.2	7.6	9.6	13.2	10.1
PH	5.70	5.60	5.60	5.60	5.62
SPECIFIC GRAVITY	1.082	1.088	1.090	1.090	1.088
RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	13.0	8.2	8.1	9.5	9.7
BISULFATE SULFUR, G/L	79.8	81.1	83.1	81.0	81.3
SULFATE SULFUR, G/L	13.4	13.9	12.6	11.5	12.9
PH	5.40	5.40	5.40	5.40	5.40
SPECIFIC GRAVITY	1.144	1.146	1.146	1.146	1.146
G-2 ELEMENT					
SULFITE SULFUR, G/L	16.3	16.3	12.4	15.6	15.1
BISULFATE SULFUR, G/L	61.6	62.3	61.6	61.6	61.8
SULFATE SULFUR, G/L	11.3	10.6	12.8	9.6	11.1
PH	5.60	5.70	5.70	5.70	5.68
SPECIFIC GRAVITY	1.124	1.126	1.126	1.126	1.126
G-3 ELEMENT					
SULFITE SULFUR, G/L	8.8	12.9	6.3	4.7	8.2
BISULFATE SULFUR, G/L	45.4	42.2	46.8	45.4	45.0
SULFATE SULFUR, G/L	7.9	8.0	10.8	12.8	9.9
PH	5.60	5.60	5.60	5.60	5.60
SPECIFIC GRAVITY	1.090	1.090	1.090	1.090	1.090
PRODUCT LIQUOR FROM SCRUBBER					
SULFITE SULFUR, G/L	8.0	11.6	11.0	11.6	10.6
BISULFITE SULFUR, G/L	71.4	73.4	74.0	73.4	73.0
SULFATE SULFUR, G/L	15.4	10.8	12.8	11.8	12.7
PH	5.60	5.60	5.60	5.60	5.60
SPECIFIC GRAVITY	1.138	1.138	1.140	1.140	1.139
PRODUCT BLEEDOFF, GPM	3.3	3.3	3.3	3.3	3.3

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AMMONIA ABSORPTION PILOT PLANT TEST NO.RST-8   .2-1-71


                                                          SAMPLE PERIOD
                                                A         B          C          D         MEAN

GAS TO SCRUBBER
  FLOW RATE, CFM AT 120 F                     2964.     2964.      2964.      2964.      2964.
  TEMPERATURE, F                              210.0     210.0      210.0      210.0      210.0
  DUST, GRAINS/CU.FT.,DRY BASIS              3.2200    3.2200     3.2200     3.2200     3.2200
  SO2, PPM                                    2760.     2760.      2720.      2760.      2750.
  EXCESS AIR, PERCENT OXYGEN                    -         -          -          -          -

GAS FROM SCRUBBER
  G-1 ELEMENT
    SO2, PPM                                  1440.     1480.      1480.      1480.      1470.

  G-2 ELEMENT
    SO2, PPM                                   480.      410.       410.       410.       427.

  G-3 ELEMENT
    SO2, PPM                                   340.      335.       330.       320.       331.
    NH3, PPM                                    -         -          -          -          -
    DUST, GRAINS/CU.FT.                      0.0028    0.0028     0.0028     0.0028     0.0028
    TEMPERATURE, F
      WET-BULB                                  94.       93.        94.        95.        94.
      DRY-BULB                                  96.       96.        96.        97.        96.

PERCENT SO2 REMOVAL                           87.68     87.86      87.87      88.41      87.95

MAKEUP LIQUOR TO SCRUBBER
  SULFITE SULFUR, G/L                          29.4      30.8       29.8       30.4       30.1
  BISULFITE SULFUR, G/L                        48.7      49.3       49.3       48.7       49.0
  SULFATE SULFUR, G/L                          12.7      11.7       12.7       12.7       12.4
  PH                                           6.20      6.20       6.10       6.10       6.15
  SPECIFIC GRAVITY                            1.138     1.140      1.140      1.140      1.140
  FOWARD FEED, GPM                              5.0       5.0        5.0        5.0        5.0
  PERCENT FOWARD FLOW TO G-3                     6.        6.         6.         6.         6.

RECIRCULATION RATE, GPM
  G-1                                           24.       24.        24.        24.        24.
  G-2                                           18.       18.        18.        18.        18.
  G-3                                           18.       18.        18.        18.        18.

RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS
  G-1 ELEMENT
    SULFITE SULFUR, G/L                        22.5      13.4       17.4       18.8       18.0
    BISULFATE SULFUR, G/L                      62.3      61.7       64.3       63.6       63.0
    SULFATE SULFUR, G/L                         9.0      11.7       14.1       12.4       11.8
    PH                                         5.90      5.80       5.80       5.80       5.83
    SPECIFIC GRAVITY                          1.136     1.136      1.135      1.136      1.136

  G-2 ELEMENT
    SULFITE SULFUR, G/L                        22.1      20.6       21.1       18.7       20.6
    BISULFATE SULFUR, G/L                      52.6      53.2       53.2       55.2       53.6
    SULFATE SULFUR, G/L                         9.1      20.0       12.5       11.9       13.4
    PH                                         5.90      5.90       5.90       5.90       5.90
    SPECIFIC GRAVITY                          1.122     1.124      1.124      1.124      1.124

  G-3 ELEMENT
    SULFITE SULFUR, G/L                         6.9       7.5        7.7        7.7        7.4
    BISULFATE SULFUR, G/L                      37.6      36.3       37.0       37.0       37.0
    SULFATE SULFUR, G/L                         8.4       8.1       11.2        8.2        9.0
    PH                                         5.80      5.40       5.70       5.70       5.65
    SPECIFIC GRAVITY                          1.088     1.076      1.076      1.076      1.079

RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS
  G-1 ELEMENT
    SULFITE SULFUR, G/L                         6.9       7.5       15.3       11.3       10.3
    BISULFATE SULFUR, G/L                      83.1      82.4       84.4       85.7       83.9
    SULFATE SULFUR, G/L                        18.8      18.9       11.1       13.8       15.6
    PH                                         5.50      5.50       5.50       5.50       5.50
    SPECIFIC GRAVITY                          1.156     1.156      1.156      1.160      1.157

  G-2 ELEMENT
    SULFITE SULFUR, G/L                        -1.2       3.8       10.7       12.1        6.4
    BISULFATE SULFUR, G/L                      71.8      71.8       57.1       57.6       64.6
    SULFATE SULFUR, G/L                        14.2      11.2       18.0       16.1       14.9
    PH                                         5.70      6.00       6.00       6.00       5.93
    SPECIFIC GRAVITY                          1.126     1.125      1.126      1.128      1.127

  G-3 ELEMENT
    SULFITE SULFUR, G/L                         4.6       4.3        6.2        6.1        5.3
    BISULFATE SULFUR, G/L                      37.6      37.6       37.6       38.8       37.9
    SULFATE SULFUR, G/L                        13.7       8.0        7.1        7.2        9.0
    PH                                         5.60      5.70       5.70       5.70       5.68
    SPECIFIC GRAVITY                          1.090     1.080      1.078      1.080      1.082

PRODUCT LIQUOR FROM SCRUBBER
  SULFITE SULFUR, G/L                          15.8      17.7       17.7       18.1       17.3
  BISULFITE SULFUR, G/L                        64.9      64.3       64.3       63.6       64.3
  SULFATE SULFUR, G/L                          14.1      11.8       11.6       12.1       12.4
  PH                                           5.70      5.70       5.70       5.70       5.70
  SPECIFIC GRAVITY                            1.138     1.138      1.138      1.136      1.138
  PRODUCT BLEEDOFF, GPM                         6.0       6.0        6.0        6.0        6.0
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AMMONIA ABSORPTION PILOT PLANT TEST NO.RST-9 ,2-4-71

	SAMPLE PERIOD A	B	C	D	MEAN
GAS TO SCRUBBER					
FLOW RATE, CFM AT 120 F	2912.	2912.	2912.	2912.	2912.
TEMPERATURE, F	188.0	204.0	212.0	210.0	203.5
DUST, GRAINS/CU.FT.,DRY BASIS	3.3400	3.3400	3.3400	3.3400	3.3400
SO2, PPM	2440.	2440.	2440.	2440.	2440.
EXCESS AIR, PERCENT OXYGEN	6.	6.	6.	6.	6.
GAS FROM SCRUBBER					
G-1 ELEMENT					
SO2, PPM	960.	840.	840.	800.	860.
G-2 ELEMENT					
SO2, PPM	320.	320.	260.	260.	290.
G-3 ELEMENT					
SO2, PPM	200.	200.	200.	220.	205.
NH3, PPM	-	-	-	-	-
DUST, GRAINS/CU.FT.	0.0042	0.0042	0.0042	0.0042	0.0042
TEMPERATURE, F					
WET-BULB	104.	104.	104.	104.	104.
DRY-BULB	106.	106.	106.	106.	106.
PERCENT SO2 REMOVAL	91.80	91.80	91.80	90.98	91.60
MAKEUP LIQUOR TO SCRUBBER					
SULFITE SULFUR, G/L	59.7	51.5	45.1	47.3	50.9
BISULFITE SULFUR, G/L	53.9	54.1	57.3	59.3	56.1
SULFATE SULFUR, G/L	29.5	34.1	35.3	36.1	33.8
PH	6.00	6.40	6.00	6.20	6.15
SPECIFIC GRAVITY	1.206	1.208	1.210	1.210	1.208
FORWARD FEED, GPM	3.0	3.0	3.0	3.0	3.0
PERCENT FORWARD FLOW TO G-3	6.	6.	6.	6.	6.
RECIRCULATION RATE, GPM					
G-1	30.	30.	30.	30.	30.
G-2	18.	18.	18.	18.	18.
G-3	18.	18.	18.	18.	18.
RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	48.9	49.4	41.2	47.4	46.7
BISULFATE SULFUR, G/L	78.6	75.9	76.6	76.6	76.9
SULFATE SULFUR, G/L	15.2	14.4	24.9	18.7	18.3
PH	6.00	6.10	6.10	6.10	6.07
SPECIFIC GRAVITY	1.204	1.204	1.206	1.208	1.205
G-2 ELEMENT					
SULFITE SULFUR, G/L	54.7	54.3	46.8	54.3	52.5
BISULFATE SULFUR, G/L	61.6	61.6	61.0	61.0	76.9
SULFATE SULFUR, G/L	14.5	13.9	23.0	15.5	16.7
PH	6.10	6.10	6.10	6.10	6.10
SPECIFIC GRAVITY	1.190	1.192	1.194	1.194	1.193
G-3 ELEMENT					
SULFITE SULFUR, G/L	33.9	37.4	34.2	40.7	36.5
BISULFATE SULFUR, G/L	45.4	46.1	46.1	46.1	45.9
SULFATE SULFUR, G/L	11.5	11.3	17.5	11.0	12.8
PH	6.10	6.00	6.20	6.10	6.10
SPECIFIC GRAVITY	1.142	1.146	1.148	1.150	1.147
RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	31.8	32.3	35.4	33.7	33.3
BISULFATE SULFUR, G/L	85.0	87.0	88.9	89.6	87.6
SULFATE SULFUR, G/L	10.0	14.4	15.4	18.4	14.6
PH	5.70	5.80	5.90	5.80	5.80
SPECIFIC GRAVITY	1.184	1.194	1.200	1.204	1.196
G-2 ELEMENT					
SULFITE SULFUR, G/L	39.3	42.6	43.2	42.5	41.9
BISULFATE SULFUR, G/L	61.0	62.3	63.0	63.0	62.3
SULFATE SULFUR, G/L	12.5	12.9	12.6	15.3	13.3
PH	5.90	5.90	5.80	5.90	5.88
SPECIFIC GRAVITY	1.172	1.174	1.178	1.178	1.175
G-3 ELEMENT					
SULFITE SULFUR, G/L	14.9	17.1	18.5	18.8	17.3
BISULFATE SULFUR, G/L	35.7	36.4	37.0	37.0	36.5
SULFATE SULFUR, G/L	8.2	7.4	8.4	10.1	8.5
PH	5.80	5.90	5.90	5.90	5.88
SPECIFIC GRAVITY	1.090	1.096	1.098	1.100	1.096
PRODUCT LIQUOR FROM SCRUBBER					
SULFITE SULFUR, G/L	51.9	41.2	41.8	46.1	45.3
BISULFITE SULFUR, G/L	68.3	68.3	70.2	71.6	69.6
SULFATE SULFUR, G/L	20.5	33.2	38.7	27.0	27.9
PH	6.10	6.10	6.10	6.00	6.07
SPECIFIC GRAVITY	1.204	1.204	1.204	1.204	1.204
PRODUCT BLEEDOFF, GPM	3.6	3.6	3.6	3.6	3.6

AMMONIA ABSORPTION PILOT PLANT TEST NO.RST-9R ,APRIL 2,1971

	SAMPLE PERIOD				
	A	B	C	D	MEAN
GAS TO SCRUBBER					
FLOW RATE, CFM AT 120 F	3080.	3080.	3080.	3080.	3080.
TEMPERATURE, F	210.0	212.0	212.0	210.0	211.0
DUST, GRAINS/CU.FT..DRY BASIS	3.6970	3.6970	3.6970	3.6970	3.6970
SO2, PPM	2600.	2600.	2720.	2720.	2660.
EXCESS AIR, PERCENT OXYGEN	3.	4.	4.	4.	4.
GAS FROM SCRUBBER					
G-1 ELEMENT					
SO2, PPM	1040.	1040.	1040.	1040.	1040.
G-2 ELEMENT					
SO2, PPM	485.	490.	350.	350.	419.
G-3 ELEMENT					
SO2, PPM	305.	240.	240.	240.	256.
NH3, PPM	206.	206.	206.	206.	206.
DUST, GRAINS/CU.FT.	0.1464	0.1464	0.1464	0.1464	0.1464
TEMPERATURE, F					
WET-BULB	110.	110.	109.	109.	110.
DRY-BULB	113.	111.	109.	109.	111.
PERCENT SO2 REMOVAL	88.27	90.77	91.18	91.18	90.35
MAKEUP LIQUOR TO SCRUBBER					
SULFITE SULFUR, G/L	76.9	75.6	78.7	79.4	77.6
BISULFITE SULFUR, G/L	70.1	70.4	70.3	70.6	70.3
SULFATE SULFUR, G/L	11.0	12.0	9.0	9.0	10.3
PH	6.20	6.19	6.20	6.22	6.20
SPECIFIC GRAVITY	1.229	1.229	1.228	1.229	1.229
FOWARD FEED, GPM	3.0	3.0	3.0	3.0	3.0
PERCENT FOWARD FLOW TO G-3	6.	6.	6.	6.	6.
RECIRCULATION RATE, GPM					
G-1	30.	30.	30.	30.	30.
G-2	18.	18.	18.	18.	18.
G-3	18.	18.	18.	18.	18.
RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	47.0	51.0	50.0	53.0	50.2
BISULFATE SULFUR, G/L	103.0	104.0	106.0	106.0	104.7
SULFATE SULFUR, G/L	8.0	6.0	8.0	6.0	7.0
PH	5.70	5.76	5.78	5.75	5.75
SPECIFIC GRAVITY	1.233	1.235	1.236	1.236	1.235
G-2 ELEMENT					
SULFITE SULFUR, G/L	55.3	59.0	58.6	58.7	57.9
BISULFATE SULFUR, G/L	75.7	74.0	74.4	73.3	104.7
SULFATE SULFUR, G/L	9.0	6.0	6.0	4.0	6.2
PH	6.00	6.00	6.00	5.98	5.99
SPECIFIC GRAVITY	1.201	1.202	1.203	1.202	1.202
G-3 ELEMENT					
SULFITE SULFUR, G/L	27.7	26.1	25.6	26.2	26.4
BISULFATE SULFUR, G/L	53.2	50.2	49.5	48.4	50.3
SULFATE SULFUR, G/L	1.0	3.8	4.1	5.0	3.5
PH	5.78	5.81	5.85	5.88	5.83
SPECIFIC GRAVITY	1.122	1.120	1.120	1.118	1.120
RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	49.0	51.0	53.0	54.0	51.8
BISULFATE SULFUR, G/L	109.0	111.0	111.0	111.0	110.5
SULFATE SULFUR, G/L	8.0	6.0	4.0	6.0	6.0
PH	5.70	5.70	5.68	5.72	5.70
SPECIFIC GRAVITY	1.241	1.242	1.243	1.243	1.242
G-2 ELEMENT					
SULFITE SULFUR, G/L	56.2	58.6	60.6	60.6	59.0
BISULFATE SULFUR, G/L	77.8	75.4	75.4	74.4	75.8
SULFATE SULFUR, G/L	7.0	6.0	5.0	5.0	5.8
PH	5.92	5.95	5.97	5.95	5.95
SPECIFIC GRAVITY	1.202	1.204	1.204	1.203	1.203
G-3 ELEMENT					
SULFITE SULFUR, G/L	24.7	25.5	26.4	27.2	26.0
BISULFATE SULFUR, G/L	53.9	52.2	50.8	49.5	51.6
SULFATE SULFUR, G/L	5.1	6.2	6.0	5.9	5.8
PH	5.80	5.81	5.85	5.85	5.83
SPECIFIC GRAVITY	1.124	1.123	1.120	1.120	1.122
PRODUCT LIQUOR FROM SCRUBBER					
SULFITE SULFUR, G/L	48.0	49.0	49.0	50.0	49.0
BISULFITE SULFUR, G/L	104.0	104.0	105.0	106.0	104.7
SULFATE SULFUR, G/L	7.0	9.0	10.0	10.0	9.0
PH	5.75	5.78	5.78	5.75	5.77
SPECIFIC GRAVITY	1.231	1.235	1.236	1.236	1.235
PRODUCT BLEEDOFF, GPM	3.4	3.4	3.4	3.4	3.4

AMMONIA ABSORPTION PILOT PLANT TEST NO.RST-10 ,2-4-71

	SAMPLE PERIOD				
	A	B	C	D	MEAN
GAS TO SCRUBBER					
FLOW RATE, CFM AT 120 F	2808.	2860.	2834.	2808.	2828.
TEMPERATURE, F	180.0	170.0	180.0	180.0	181.5
DUST, GRAINS/CU.FT.,DRY BASIS	2.8600	2.8600	2.8600	2.8600	2.8600
SO2, PPM	2480.	2480.	2600.	2600.	2540.
EXCESS AIR, PERCENT OXYGEN	6.	6.	6.	6.	6.
GAS FROM SCRUBBER					
G-1 ELEMENT					
SO2, PPM	600.	600.	680.	760.	660.
G-2 ELEMENT					
SO2, PPM	230.	315.	410.	410.	341.
G-3 ELEMENT					
SO2, PPM	300.	300.	420.	480.	375.
NH3, PPM	-	-	-	-	-
DUST, GRAINS/CU.FT.	0.0008	0.0008	0.0008	0.0008	0.0008
TEMPERATURE, F					
WET-BULB	100.	100.	100.	99.	100.
DRY-BULB	102.	102.	102.	101.	102.
PERCENT SO2 REMOVAL	87.90	87.90	83.85	81.54	85.30
MAKEUP LIQUOR TO SCRUBBER					
SULFITE SULFUR, G/L	45.1	47.3	59.7	51.5	50.9
BISULFITE SULFUR, G/L	57.3	59.3	53.5	54.1	56.1
SULFATE SULFUR, G/L	35.3	36.1	29.5	34.1	33.8
PH	6.00	6.20	6.00	6.40	6.15
SPECIFIC GRAVITY	1.210	1.210	1.206	1.206	1.208
FORWARD FEED, GPM	9.0	9.0	9.0	9.0	9.0
PERCENT FORWARD FLOW TO G-3	12.	12.	12.	12.	12.
RECIRCULATION RATE, GPM					
G-1	30.	30.	30.	30.	30.
G-2	18.	18.	18.	18.	18.
G-3	18.	18.	18.	18.	18.
RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	26.4	34.7	38.1	38.8	34.5
BISULFATE SULFUR, G/L	79.3	79.3	80.5	84.6	80.9
SULFATE SULFUR, G/L	21.2	15.9	17.1	15.3	17.4
PH	5.80	5.80	5.90	5.80	5.83
SPECIFIC GRAVITY	1.182	1.188	1.196	1.200	1.192
G-2 ELEMENT					
SULFITE SULFUR, G/L	36.1	43.7	48.3	41.5	42.4
BISULFATE SULFUR, G/L	54.8	58.7	58.7	60.0	80.9
SULFATE SULFUR, G/L	23.0	15.5	11.8	19.3	17.4
PH	6.00	6.00	6.00	5.90	5.98
SPECIFIC GRAVITY	1.170	1.174	1.176	1.180	1.175
G-3 ELEMENT					
SULFITE SULFUR, G/L	12.9	14.9	10.1	17.5	13.9
BISULFATE SULFUR, G/L	32.3	34.2	35.9	36.1	34.5
SULFATE SULFUR, G/L	7.8	0.9	17.3	13.3	9.8
PH	6.00	6.00	5.80	5.90	5.93
SPECIFIC GRAVITY	1.086	1.092	1.096	1.100	1.094
RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	46.0	43.8	44.8	43.1	44.4
BISULFATE SULFUR, G/L	85.1	85.1	85.7	83.8	84.9
SULFATE SULFUR, G/L	16.6	19.8	17.2	21.8	18.9
PH	6.00	5.90	5.90	6.00	5.95
SPECIFIC GRAVITY	1.214	1.214	1.212	1.214	1.214
G-2 ELEMENT					
SULFITE SULFUR, G/L	54.1	53.5	54.7	51.2	53.4
BISULFATE SULFUR, G/L	61.9	62.5	61.9	61.2	61.9
SULFATE SULFUR, G/L	14.8	15.7	15.1	21.3	16.7
PH	5.90	6.00	6.30	6.30	6.13
SPECIFIC GRAVITY	1.194	1.196	1.194	1.196	1.195
G-3 ELEMENT					
SULFITE SULFUR, G/L	35.3	34.4	39.4	38.5	36.9
BISULFATE SULFUR, G/L	45.2	45.8	46.4	46.4	46.0
SULFATE SULFUR, G/L	14.3	15.6	14.0	14.9	14.7
PH	5.90	6.00	5.90	6.00	5.95
SPECIFIC GRAVITY	1.146	1.148	1.150	1.152	1.149
PRODUCT LIQUOR FROM SCRUBBER					
SULFITE SULFUR, G/L	13.2	13.6	14.5	14.8	14.0
BISULFITE SULFUR, G/L	74.1	80.5	81.2	89.6	81.4
SULFATE SULFUR, G/L	36.5	36.7	40.0	70.3	45.9
PH	5.90	6.00	5.80	5.80	5.88
SPECIFIC GRAVITY	1.182	1.192	1.200	1.202	1.194
PRODUCT BLOWDOFF, GPM	9.7	9.7	9.7	9.7	9.7

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AMMONIA ABSORPTION PILOT PLANT TEST NO.RST-10R ,APRIL 2,1970

                                                        SAMPLE PERIOD
                                            A           B           C           D         MEAN

GAS TO SCRUBBER
  FLOW RATE, CFM AT 120 F
  TEMPERATURE, F                          3050,       3050,       3050,       3050,       3050,
  DUST, GRAINS/CU.FT..DRY BASIS           190,0       180,0       180,0       180,0       182,5
  SO2, PPM                              4,1475      4,1475      4,1475      4,1475      4,1475
  EXCESS AIR, PERCENT OXYGEN              2720,       2720,       2720,       2720,       2720,
                                            4,          3,          4,          4,          4,

GAS FROM SCRUBBER
  Q-1 ELEMENT
    SO2, PPM
                                           700,        700,        700,        700,        700,

  Q-2 ELEMENT
    SO2, PPM
                                           200,        200,        180,        180,        190,

  Q-3 ELEMENT
    SO2, PPM
    NH3, PPM                                72,         72,         72,         72,         72,
    DUST, GRAINS/CU.FT.                    393,        393,        393,        393,        393,
    TEMPERATURE, F                      0,7639      0,7639      0,7639      0,7639      0,7639
      WET-BULB
      DRY-BULB                             111,        110,        108,        108,        109,
                                           112,        111,        108,        108,        110,

PERCENT SO2 REMOVAL                      97,35       97,35       97,35       97,35       97,35

MAKEUP LIQUOR TO SCRUBBER
  SULFITE SULFUR, G/L                     85,5        83,1        83,1        84,0        83,9
  BISULFITE SULFUR, G/L                   68,3        69,0        69,0        68,7        68,7
  SULFATE SULFUR, G/L                      9,9        11,6        12,6        11,3        11,4
  PH                                        -           -           -           -           -
  SPECIFIC GRAVITY                       1,232       1,232       1,231       1,232       1,232
  FORWARD FEED, GPM                        5,0         5,0         5,0         5,0         5,0
  PERCENT FORWARD FLOW TO Q-3              12,         12,         12,         12,         12,

RECIRCULATION RATE, GPM
  Q-1
  Q-2                                      30,         30,         30,         30,         30,
  Q-3                                      10,         10,         10,         10,         10,
                                           10,         10,         10,         10,         10,

RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS
  Q-1 ELEMENT
    SULFITE SULFUR, G/L                   60,6        63,6        64,1        63,1        62,9
    BISULFATE SULFUR, G/L                 92,8        90,2        90,9        92,2        91,5
    SULFATE SULFUR, G/L                   11,3        10,9        11,7        11,4        11,3
    PH                                      -           -           -           -           -
    SPECIFIC GRAVITY                     1,234       1,236       1,236       1,238       1,236

  Q-2 ELEMENT
    SULFITE SULFUR, G/L                   67,5        69,8        64,2        65,8        66,8
    BISULFATE SULFUR, G/L                 72,2        70,2        72,2        72,2        91,5
    SULFATE SULFUR, G/L                   11,0         9,7        13,3        11,7        11,4
    PH                                      -           -           -           -           -
    SPECIFIC GRAVITY                     1,216       1,212       1,214       1,214       1,214

  Q-3 ELEMENT
    SULFITE SULFUR, G/L                   46,2        47,2        50,2        51,7        48,8
    BISULFATE SULFUR, G/L                 56,1        56,7        57,3        57,3        56,8
    SULFATE SULFUR, G/L                    1.9         9,4         7,3         5,8         6,1
    PH                                     --           -           -           -           -
    SPECIFIC GRAVITY                     1,162       1,164       1,168       1,170       1,166

RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS
  Q-1 ELEMENT
    SULFITE SULFUR, G/L                   59,9        57,0        59,0        63,2        59,8
    BISULFATE SULFUR, G/L                102,5       103,8       103,1        99,9       102,3
    SULFATE SULFUR, G/L                   10,3         9,9         9,6         9,6         9,9
    PH                                      -           -           -           -           -
    SPECIFIC GRAVITY                     1,244       1,244       1,244       1,243       1,244

  Q-2 ELEMENT
    SULFITE SULFUR, G/L                   67,5        68,1        69,1        69,7        68,6
    BISULFATE SULFUR, G/L                 73,7        73,7        72,8        72,2        73,1
    SULFATE SULFUR, G/L                   10,5        11,9         9,8         9,8        10,5
    PH                                      -           -           -           -           -
    SPECIFIC GRAVITY                     1,214       1,214       1,214       1,216       1,215

  Q-3 ELEMENT
    SULFITE SULFUR, G/L                   47,9        47,8        50,7        51,6        49,5
    BISULFATE SULFUR, G/L                 55,4        56,1        56,1        57,4        56,3
    SULFATE SULFUR, G/L                    7,5         7,9         9,0         7,8         8,0
    PH                                      -           -           -           -           -
    SPECIFIC GRAVITY                     1,164       1,170       1,170       1,174       1,170

PRODUCT LIQUOR FROM SCRUBBER
  SULFITE SULFUR, G/L                     62,9        63,9        62,2        63,2        63,0
  BISULFITE SULFUR, G/L                   90,2        90,2        92,8        92,8        91,5
  SULFATE SULFUR, G/L                     11,6        11,6        10,7         8,7        10,7
  PH                                        -           -           -           -           -
  SPECIFIC GRAVITY                       1,232       1,234       1,236       1,238       1,235
  PRODUCT BLEEDOFF, GPM                    5,6         5,6         5,6         5,6         5,6
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        AMMONIA ABSORPTION PILOT PLANT TEST NO.RST-11  ,FEB 12, 1971


                                                             SAMPLE PERIOD
                                                A            B           C           D          MEAN

  GAS TO SCRUBBER
    FLOW RATE, CFM AT 120 F                   2704.        2756.       2704.       2704.       2717.
    TEMPERATURE, F                            212,0        210,0       212,0       209,0       210,8
    DUST, GRAINS/CU,FT.,DRY BASIS            0,6625       0,6625      0,6625      0,6625      0,6625
    SO2, PPM                                  2640.        2640.       2640.       2640.       2640.
    EXCESS AIR, PERCENT OXYGEN                   4.           4.          4.          5.          4.

  GAS FROM SCRUBBER
    G-1 ELEMENT
      SO2, PPM                                1000.        1000.       1000.       1000.       1000.

    G-2 ELEMENT
      SO2, PPM                                 820.         820.        820.        820.        820.

    G-3 ELEMENT
      SO2, PPM                                 520.         520.        520.        520.        520.
      NH3, PPM                                   -            -           -           -           -
      DUST, GRAINS/CU,FT.                    0,0080       0,0080      0.0080      0,0080      0,0080
      TEMPERATURE, F
        WET-BULB                               105.         105.        104.        104.        105.
        DRY-BULB                               105.         106.        106.        105.        105.

  PERCENT SO2 REMOVAL                         80,30        80,30       80,30       80,30       80,30

  MAKEUP LIQUOR TO SCRUBBER
    SULFITE SULFUR, G/L                        50,1         53,8        53,1        54,5        52,9
    BISULFITE SULFUR, G/L                      83,8         83,8        83,8        83,1        83,6
    SULFATE SULFUR, G/L                        17,8         14,1        13,8        13,1        14,7
    PH                                         6,00         6,20        6,20        6,20        6,15
    SPECIFIC GRAVITY                          1,220        1,218       1,218       1,214       1,218
    FOWARD FEED, GPM                            3,0          3,0         3,0         3,0         3,0
    PERCENT FOWARD FLOW TO G-3                  12.          12.         12.         12.         12.

  RECIRCULATION RATE, GPM
    G-1                                         30.          30.         30.         30.         30.
    G-2                                         18.          18.         18.         18.         18.
    G-3                                         18.          18.         18.         18.         18.

  RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS
    G-1 ELEMENT
      SULFITE SULFUR, G/L                      14,2         13,3        26,7        15,6        17,5
      BISULFATE SULFUR, G/L                    98,6        101,8       100,5       102,5       100,9
      SULFATE SULFUR, G/L                       6,0          7,9        21,5        29,6        16,3
      PH                                       6,10         6,00        6,00        5,90        6,00
      SPECIFIC GRAVITY                        1,200        1,204       1,208       1,210       1,206

    G-2 ELEMENT
      SULFITE SULFUR, G/L                      22,3         28,2        31,5        18,4        25,1
      BISULFATE SULFUR, G/L                    77,3         75,4        79,3        80,6       100,9
      SULFATE SULFUR, G/L                       6,5          5,8        17,9        30,7        15,2
      PH                                       6,20         6,20        6,20        6,20        6,20
      SPECIFIC GRAVITY                        1,180        1,182       1,184       1,186       1,183

    G-3 ELEMENT
      SULFITE SULFUR, G/L                      11,5         14,2        14,5         4,3        11,1
      BISULFATE SULFUR, G/L                    54,8         55,4        54,8        54,1        54,8
      SULFATE SULFUR, G/L                      13,5         -5,1        18,5        22,4        12,3
      PH                                       6,10         6,10        6,10        6,10        6,10
      SPECIFIC GRAVITY                        1,116        1,116       1,118       1,120       1,117

  RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS
    G-1 ELEMENT
      SULFITE SULFUR, G/L                      29,8         34,1        26,7        15,0        26,4
      BISULFATE SULFUR, G/L                   101,8        100,5       107,6       105,7       103,9
      SULFATE SULFUR, G/L                      13,1         14,1        18,4        32,0        19,4
      PH                                       5,90         5,80        5,80        5,80        5,83
      SPECIFIC GRAVITY                        1,198        1.204       1,212       1,216       1,207

    G-2 ELEMENT
      SULFITE SULFUR, G/L                      32,7         30,0        36,3        18,2        29,3
      BISULFATE SULFUR, G/L                    83,1         81,2        81,8        83,1        82,3
      SULFATE SULFUR, G/L                      15,9         17,5        12,6        20,4        18,9
      PH                                       6,00         6,00        6,00        6,00        6,00
      SPECIFIC GRAVITY                        1,180        1,180       1,184       1,190       1,183

    G-3 ELEMENT
      SULFITE SULFUR, G/L                      13,9         15,8        13,2         3,7        11,6
      BISULFATE SULFUR, G/L                    55,4         56,1        56,1        56,7        56,1
      SULFATE SULFUR, G/L                      10,5          7,9        13,5        23,4        13,8
      PH                                       6,00         5,90        5,90        5,90        5,93
      SPECIFIC GRAVITY                        1,116        1,116       1,122       1,122       1,119

  PRODUCT LIQUOR FROM SCRUBBER
    SULFITE SULFUR, G/L                        25,2         30,8        28,8        -3,4        20,3
    BISULFITE SULFUR, G/L                     100,5         99,2       102,5       105,7       102,0
    SULFATE SULFUR, G/L                        18,0         14,7        17,4        47,4        24,4
    PH                                         5,90         5,90        5,90        5,90        5,90
    SPECIFIC GRAVITY                          1,200        1,204       1,208       1,210       1,205
    PRODUCT BLEEDOFF, GPM                       3,6          3,6         3,6         3,6         3,6
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AMMONIA ABSORPTION PILOT PLANT TEST NO.NST-12 ,FEB 12, 1971

	SAMPLE PERIOD				
	A	B	C	D	MEAN
GAS TO SCRUBBER					
FLOW RATE, CFM AT 120 F	2704.	2600.	2600.	2600.	2626.
TEMPERATURE, F	180.0	180.0	180.0	180.0	180.0
DUST, GRAINS/CU.FT.,DRY BASIS	0.4951	0.4951	0.4951	0.4951	0.4951
SO2, PPM	2480.	2480.	2480.	2480.	2480.
EXCESS AIR, PERCENT OXYGEN	4.	4.	4.	5.	4.
GAS FROM SCRUBBER					
G-1 ELEMENT					
SO2, PPM	1040.	1040.	1160.	1160.	1100.
G-2 ELEMENT					
SO2, PPM	550.	550.	605.	605.	577.
G-3 ELEMENT					
SO2, PPM	505.	505.	550.	550.	527.
NH3, PPM	-	-	-	-	-
DUST, GRAINS/CU.FT.	0.0050	0.0050	0.0050	0.0050	0.0050
TEMPERATURE, F					
WET-BULB	98.	98.	99.	100.	99.
DRY-BULB	100.	100.	101.	102.	101.
PERCENT SO2 REMOVAL	79.64	79.64	77.82	77.82	78.73
MAKEUP LIQUOR TO SCRUBBER					
SULFITE SULFUR, G/L	53.1	54.5	50.1	53.8	52.9
BISULFITE SULFUR, G/L	83.8	83.1	83.8	83.8	83.6
SULFATE SULFUR, G/L	13.8	13.1	17.8	14.1	14.7
PH	6.20	6.20	6.00	6.20	6.15
SPECIFIC GRAVITY	1.218	1.214	1.220	1.218	1.218
FOWARD FEED, GPM	5.0	5.0	5.0	5.0	5.0
PERCENT FOWARD FLOW TO G-3	6.	6.	6.	6.	6.
RECIRCULATION RATE, GPM					
G-1	30.	30.	30.	30.	30.
G-2	18.	18.	18.	18.	18.
G-3	18.	18.	18.	18.	18.
RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	45.1	38.0	46.4	37.0	41.6
BISULFATE SULFUR, G/L	97.3	98.6	92.8	94.1	95.7
SULFATE SULFUR, G/L	10.3	14.1	12.5	18.6	13.9
PH	6.20	6.20	6.10	6.10	6.15
SPECIFIC GRAVITY	1.208	1.206	1.209	1.210	1.208
G-2 ELEMENT					
SULFITE SULFUR, G/L	40.9	44.8	43.1	41.2	42.5
BISULFATE SULFUR, G/L	82.5	82.5	82.5	81.8	95.7
SULFATE SULFUR, G/L	16.3	12.4	15.1	17.7	15.4
PH	6.00	6.10	6.10	6.10	6.07
SPECIFIC GRAVITY	1.196	1.196	1.198	1.198	1.197
G-3 ELEMENT					
SULFITE SULFUR, G/L	22.6	21.6	21.1	20.1	21.3
BISULFATE SULFUR, G/L	58.6	59.3	59.3	59.3	59.1
SULFATE SULFUR, G/L	10.6	9.9	13.4	13.4	11.8
PH	6.00	5.90	5.90	5.90	5.93
SPECIFIC GRAVITY	1.132	1.132	1.134	1.134	1.133
RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	35.7	39.3	27.3	30.6	33.2
BISULFATE SULFUR, G/L	104.4	99.9	102.5	103.1	102.5
SULFATE SULFUR, G/L	16.6	15.5	26.9	20.0	19.8
PH	5.80	5.90	5.90	5.80	5.85
SPECIFIC GRAVITY	1.212	1.212	1.212	1.214	1.213
G-2 ELEMENT					
SULFITE SULFUR, G/L	39.9	42.5	36.4	43.8	40.7
BISULFATE SULFUR, G/L	83.1	83.1	81.8	82.5	82.6
SULFATE SULFUR, G/L	16.7	15.1	22.5	13.4	16.9
PH	5.90	6.00	6.00	6.00	5.98
SPECIFIC GRAVITY	1.198	1.195	1.196	1.196	1.196
G-3 ELEMENT					
SULFITE SULFUR, G/L	17.5	21.8	19.4	23.5	20.5
BISULFATE SULFUR, G/L	60.0	60.0	58.6	59.3	59.5
SULFATE SULFUR, G/L	15.3	13.0	15.8	11.0	13.8
PH	5.90	5.90	5.90	5.90	5.90
SPECIFIC GRAVITY	1.132	1.132	1.134	1.132	1.133
PRODUCT LIQUOR FROM SCRUBBER					
SULFITE SULFUR, G/L	37.7	37.7	40.5	38.0	38.5
BISULFITE SULFUR, G/L	94.7	97.3	95.4	95.4	95.7
SULFATE SULFUR, G/L	21.3	16.7	14.8	16.3	17.3
PH	6.10	6.10	6.00	6.00	6.05
SPECIFIC GRAVITY	1.212	1.212	1.212	1.208	1.211
PRODUCT BLEEDOFF, GPM	5.7	5.7	5.7	5.7	5.7

AMMONIA ABSORPTION PILOT PLANT TEST NO.HP-2 ,2-17-71

	SAMPLE PERIOD				
	A	B	C	D	MEAN
GAS TO SCRUBBER					
FLOW RATE, CFM AT 120 F	2850.	2800.	2850.	2850.	2837.
TEMPERATURE, F	200.0	195.0	196.0	196.0	196.7
DUST, GRAINS/CU.FT., DRY BASIS	1.1836	1.1836	1.1836	1.1836	1.1836
SO2, PPM	2480.	2480.	2640.	2640.	2560.
EXCESS AIR, PERCENT OXYGEN	4.	4.	4.	4.	4.
GAS FROM SCRUBBER					
G-1 ELEMENT					
SO2, PPM	1200.	1200.	1200.	1200.	1200.
G-2 ELEMENT					
SO2, PPM	600.	600.	520.	550.	567.
G-3 ELEMENT					
SO2, PPM	400.	400.	490.	510.	450.
NH3, PPM					
DUST, GRAINS/CU.FT.	0.0092	0.0092	0.0092	0.0092	0.0092
TEMPERATURE, F					
WET-BULB	108.	108.	108.	109.	108.
DRY-BULB	109.	109.	110.	110.	110.
PERCENT SO2 REMOVAL	83.87	83.87	81.44	80.68	82.47
MAKEUP LIQUOR TO SCRUBBER					
SULFITE SULFUR, G/L	43.6	38.6	43.6	38.6	41.1
BISULFITE SULFUR, G/L	56.5	56.5	56.5	56.5	56.5
SULFATE SULFUR, G/L	18.7	23.7	18.7	23.7	21.2
PH	6.30	6.30	6.30	6.30	6.30
SPECIFIC GRAVITY	1.180	1.180	1.180	1.180	1.180
FORWARD FEED, GPM	4.0	4.0	4.0	4.0	4.0
PERCENT FORWARD FLOW TO G-3	9.	9.	9.	9.	9.
RECIRCULATION RATE, GPM					
G-1	30.	30.	30.	30.	30.
G-2	10.	10.	10.	10.	10.
G-3	10.	10.	10.	10.	10.
RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	35.3	30.6	29.4	30.6	31.5
BISULFATE SULFUR, G/L	79.4	83.2	80.6	80.6	81.0
SULFATE SULFUR, G/L	15.0	13.9	18.7	17.5	16.3
PH	5.80	5.30	5.80	5.80	5.68
SPECIFIC GRAVITY	1.186	1.184	1.184	1.186	1.185
G-2 ELEMENT					
SULFITE SULFUR, G/L	36.8	36.1	34.1	21.1	32.0
BISULFATE SULFUR, G/L	60.3	61.0	59.7	60.3	81.0
SULFATE SULFUR, G/L	12.7	14.7	17.0	30.4	18.7
PH	6.10	6.10	6.10	6.10	6.10
SPECIFIC GRAVITY	1.166	1.166	1.166	1.166	1.166
G-3 ELEMENT					
SULFITE SULFUR, G/L	21.4	19.8	15.4	10.0	16.7
BISULFATE SULFUR, G/L	45.7	45.1	43.8	43.8	44.6
SULFATE SULFUR, G/L	10.7	12.0	17.7	23.1	15.9
PH	5.80	5.50	5.50	5.80	5.65
SPECIFIC GRAVITY	1.120	1.118	1.116	1.118	1.118
RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	27.4	25.9	28.1	28.1	27.4
BISULFATE SULFUR, G/L	88.3	87.6	89.5	87.6	88.3
SULFATE SULFUR, G/L	18.0	18.2	15.1	16.0	16.8
PH	5.90	5.90	5.80	5.80	5.85
SPECIFIC GRAVITY	1.188	1.188	1.188	1.188	1.188
G-2 ELEMENT					
SULFITE SULFUR, G/L	34.1	34.1	28.6	34.9	32.9
BISULFATE SULFUR, G/L	61.6	62.2	62.2	61.6	61.9
SULFATE SULFUR, G/L	15.1	14.5	19.0	14.3	15.7
PH	6.10	6.10	6.20	6.20	6.15
SPECIFIC GRAVITY	1.162	1.162	1.164	1.164	1.163
G-3 ELEMENT					
SULFITE SULFUR, G/L	20.5	21.4	18.6	20.4	20.2
BISULFATE SULFUR, G/L	45.7	45.7	45.7	45.1	45.6
SULFATE SULFUR, G/L	11.6	10.7	12.6	10.4	11.3
PH	6.20	6.20	6.10	6.10	6.15
SPECIFIC GRAVITY	1.118	1.118	1.118	1.118	1.118
PRODUCT LIQUOR FROM SCRUBBER					
SULFITE SULFUR, G/L	23.7	29.9	28.4	28.8	27.7
BISULFITE SULFUR, G/L	80.6	81.3	81.3	80.6	81.0
SULFATE SULFUR, G/L	23.5	17.6	21.1	18.4	20.1
PH	5.90	5.90	5.90	5.90	5.90
SPECIFIC GRAVITY	1.186	1.186	1.186	1.186	1.186
PRODUCT BLEEDOFF, GPM	5.4	5.4	5.4	5.4	5.4

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AMMONIA ABSORPTION PILOT PLANT TEST NO.NST-13  ,2-19-71


                                                        SAMPLE PERIOD
                                            A           B           C           D          MEAN

GAS TO SCRUBBER
  FLOW RATE, CFM AT 120 F
  TEMPERATURE, F                          2750,       2750,       2700,       2660,       2715,
  DUST, GRAINS/CU.FT.,DRY BASIS           212,0       214,0       211,0       210,0       211,8
  SO2, PPM                               0,5487      0,5487      0,5487      0,5487      0,5487
  EXCESS AIR, PERCENT OXYGEN              2920,       2520,       2400,       2400,       2460,
                                             5,          5,          5,          5,          5,

GAS FROM SCRUBBER
  G-1 ELEMENT
    SO2, PPM
                                           590,        590,        540,        540,        565,
  G-2 ELEMENT
    SO2, PPM
                                           115,        115,         95,         95,        105,
  G-3 ELEMENT
    SO2, PPM
    NH3, PPM                                62,         62,         29,         29,         45,
    DUST, GRAINS/CU.FT.                      -           -           -           -           -
    TEMPERATURE, F                       0,0051      0,0051      0,0051      0,0051      0,0051
      WET-BULB
      DRY-BULB                             109,        107,        107,        108,        108,
                                           109,        108,        108,        108,        108,

PERCENT SO2 REMOVAL                      97,54       97,54       98,79       98,79       98,17

MAKEUP LIQUOR TO SCRUBBER
  SULFITE SULFUR, G/L
  BISULFITE SULFUR, G/L                   31,8        31,6        26,8        28,6        29,7
  SULFATE SULFUR, G/L                     29,8        29,8        29,8        29,8        29,8
  PH                                      13,3        12,5        16,3        14,5        14,1
  SPECIFIC GRAVITY                        6,60        6,60        6,30        6,60        6,52
  FORWARD FEED, GPM                      1,116       1,116       1,118       1,118       1,117
  PERCENT FORWARD FLOW TO G-3              5,0         5,0         5,0         5,0         5,0
                                           12,         12,         12,         12,         12,

RECIRCULATION RATE, GPM
  G-1
  G-2                                       30,         30,         30,         30,         30,
  G-3                                       18,         18,         18,         18,         18,
                                            18,         18,         18,         18,         18,

RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS
  G-1 ELEMENT
    SULFITE SULFUR, G/L
    BISULFATE SULFUR, G/L                 11,3        14,0        16,7        19,0        15,2
    SULFATE SULFUR, G/L                   54,0        49,5        50,8        48,9        50,8
    PH                                    18,5        19,3        18,3        13,0        17,3
    SPECIFIC GRAVITY                      6,30        6,50        6,40        6,40        6,40
                                         1,128       1.122       1,120       1,122       1,123
  G-2 ELEMENT
    SULFITE SULFUR, G/L
    BISULFATE SULFUR, G/L                 17,2        24,8        18,2        27,1        21,8
    SULFATE SULFUR, G/L                   36,2        33,0        33,0        31,7        30,8
    PH                                    19,5        10,1        14,7         9,1        13,3
    SPECIFIC GRAVITY                      6,50        6,70        6,60        6,60        6,60
                                         1,110       1,108       1,106       1,106       1,107
  G-3 ELEMENT
    SULFITE SULFUR, G/L
    BISULFATE SULFUR, G/L                 14,5         9.2        10,8        13,5        12,0
    SULFATE SULFUR, G/L                   29,0        25,4        24,1        22,3        25,4
    PH                                     9,6        16,3        13.8        11,1        12,5
    SPECIFIC GRAVITY                      6,60        6,70        6,70        6,60        6,65
                                         1,084       1.080       1,074       1,074       1,078

RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS
  G-1 ELEMENT
    SULFITE SULFUR, G/L
    BISULFATE SULFUR, G/L                 19,0        18.0        14,0        12,1        15,8
    SULFATE SULFUR, G/L                   61.2        59.3        59,3        58,0        59,4
    PH                                    12.4        11.5        12,5        15,7        13,1
    SPECIFIC GRAVITY                      6,10        6,10        6,10        6,20        6,13
                                         1,132       1.128       1,128       1,126       1,128
  G-2 ELEMENT
    SULFITE SULFUR, G/L
    BISULFATE SULFUR, G/L                 24,6        25,0        22,9        19,4        23,0
    SULFATE SULFUR, G/L                   36,8        34,6        34,2        32,9        34,7
    PH                                    11,5        11,1        10,8        15,6        12,3
    SPECIFIC GRAVITY                      6,50        6,50        6,50        6,30        6,45
                                         1.112       1.108       1,106       1,106       1,108
  G-3 ELEMENT
    SULFITE SULFUR, G/L
    BISULFATE SULFUR, G/L                 12,8        16,9        17,5        15,8        15,8
    SULFATE SULFUR, G/L                   28,3        27,1        24,5        22,6        25,6
    PH                                    12,8         7,9         6,9         9,5         9,3
    SPECIFIC GRAVITY                      6,30        6,50        6,50        6,50        6,45
                                         1,084       1.080       1,078       1,076       1,080

PRODUCT LIQUOR FROM SCRUBBER
  SULFITE SULFUR, G/L
  BISULFITE SULFUR, G/L                   12,5        16,0        18.9        20,8        17,1
  SULFATE SULFUR, G/L                     54,0        52,1        50,8        49,5        51,6
  PH                                      18,3        13,7        12,1         6,6        12,7
  SPECIFIC GRAVITY                        6,30        6,40        6,40        6,30        6,35
  PRODUCT BLEEDOFF, GPM                  1,126       1.124       1,122       1.122       1,124
                                           5,7         5,7         5,7         5,7         5,7
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AMMONIA ABSORPTION PILOT PLANT TEST NO,HST-14 ,2-19-71

	SAMPLE PERIOD				
	A	B	C	D	MEAN
GAS TO SCRUBBER					
FLOW RATE, CFM AT 120 F	2660.	2660.	2660.	2660.	2660.
TEMPERATURE, F	180.0	179.0	180.0	180.0	179.7
DUST, GRAINS/CU.FT.,DRY BASIS	0.3997	0.3997	0.3997	0.3997	0.3997
SO2, PPM	2400.	2400.	2400.	2400.	2440.
EXCESS AIR, PERCENT OXYGEN	5.	5.	5.	5.	5.
GAS FROM SCRUBBER					
G-1 ELEMENT					
SO2, PPM	805.	805.	810.	810.	808.
G-2 ELEMENT					
SO2, PPM	180.	180.	190.	190.	185.
G-3 ELEMENT					
SO2, PPM	125.	125.	140.	140.	132.
NH3, PPM	-	-	-	-	-
DUST, GRAINS/CU.FT.	0.0050	0.0050	0.0050	0.0050	0.0050
TEMPERATURE, F					
WET-BULB	106.	107.	106.	106.	106.
DRY-BULB	108.	107.	107.	107.	107.
PERCENT SO2 REMOVAL	94.96	94.96	94.17	94.17	94.56
MAKEUP LIQUOR TO SCRUBBER					
SULFITE SULFUR, G/L	26.6	28.6	31.8	31.6	29.7
BISULFITE SULFUR, G/L	29.0	29.0	29.0	29.0	29.0
SULFATE SULFUR, G/L	16.3	14.5	13.3	12.5	14.1
PH	6.30	6.60	6.60	6.60	6.52
SPECIFIC GRAVITY	1.118	1.118	1.116	1.116	1.117
FORWARD FEED, GPM	3.0	3.0	3.0	3.0	3.0
PERCENT FORWARD FLOW TO G-3	6.	6.	6.	6.	6.
RECIRCULATION RATE, GPM					
G-1	30.	30.	30.	30.	30.
G-2	18.	18.	18.	18.	18.
G-3	18.	18.	18.	18.	18.
RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	14.8	13.5	15.8	9.7	13.5
BISULFATE SULFUR, G/L	60.3	61.6	59.1	60.9	60.5
SULFATE SULFUR, G/L	12.7	12.7	12.9	16.2	13.6
PH	5.90	5.90	5.80	5.90	5.88
SPECIFIC GRAVITY	1.128	1.128	1.128	1.126	1.127
G-2 ELEMENT					
SULFITE SULFUR, G/L	23.3	24.9	16.0	17.9	20.5
BISULFATE SULFUR, G/L	36.8	37.5	39.4	38.1	60.5
SULFATE SULFUR, G/L	11.8	8.5	14.5	13.9	12.2
PH	6.30	6.30	6.30	6.30	6.30
SPECIFIC GRAVITY	1.110	1.110	1.110	1.110	1.110
G-3 ELEMENT					
SULFITE SULFUR, G/L	12.7	11.4	11.0	5.8	10.2
BISULFATE SULFUR, G/L	25.4	26.7	27.3	28.0	26.9
SULFATE SULFUR, G/L	7.8	8.8	6.6	10.1	8.3
PH	6.30	6.20	6.20	6.10	6.20
SPECIFIC GRAVITY	1.074	1.074	1.070	1.072	1.072
RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	11.8	9.0	10.6	11.8	10.8
BISULFATE SULFUR, G/L	66.1	66.7	66.0	64.8	65.9
SULFATE SULFUR, G/L	11.9	15.9	16.2	15.2	14.8
PH	5.80	5.80	5.80	5.80	5.80
SPECIFIC GRAVITY	1.132	1.132	1.128	1.128	1.130
G-2 ELEMENT					
SULFITE SULFUR, G/L	16.3	17.6	22.1	19.8	19.0
BISULFATE SULFUR, G/L	40.7	40.0	39.0	40.0	39.9
SULFATE SULFUR, G/L	14.9	14.3	10.8	12.1	13.0
PH	6.30	6.20	6.20	6.30	6.25
SPECIFIC GRAVITY	1.112	1.110	1.106	1.106	1.109
G-3 ELEMENT					
SULFITE SULFUR, G/L	9.4	10.0	10.0	9.3	9.7
BISULFATE SULFUR, G/L	27.3	27.3	27.9	28.6	27.8
SULFATE SULFUR, G/L	11.2	10.6	9.0	9.0	9.9
PH	6.20	6.10	6.20	6.20	6.18
SPECIFIC GRAVITY	1.074	1.072	1.068	1.070	1.071
PRODUCT LIQUOR FROM SCRUBBER					
SULFITE SULFUR, G/L	10.3	8.5	9.4	10.7	9.7
BISULFITE SULFUR, G/L	59.1	60.3	59.1	59.1	59.4
SULFATE SULFUR, G/L	17.4	18.0	19.3	17.0	17.9
PH	5.90	5.90	5.90	5.90	5.90
SPECIFIC GRAVITY	1.128	1.128	1.128	1.128	1.128
PRODUCT BLEEDOFF, GPM	3.6	3.6	3.6	3.6	3.6

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AMMONIA ABSORPTION PILOT PLANT TEST NO.RST-15  ,2-26-71


                                                            SAMPLE PERIOD
                                                A           B           C           D          MEAN

GAS TO SCRUBBER
  FLOW RATE, CFM AT 120 F
  TEMPERATURE, F                              3190.       3100.       3016.       3016.       3080.
  DUST, GRAINS/CU.FT.,DRY BASIS              195,0       195,0       190,0       190,0       192,5
  SO2, PPM                                  4,9059      4,9059      4,9059      4,9059      4,9059
  EXCESS AIR, PERCENT OXYGEN                  2480.       2480.       2480.       2480.       2480.
                                                 5.          5.          5.          5.          5.

GAS FROM SCRUBBER
  G-1 ELEMENT
    SO2, PPM
                                              1480.       1480.       1480.       1480.       1480.
  G-2 ELEMENT
    SO2, PPM
                                               760.        760.        730.        730.        745.
  G-3 ELEMENT
    SO2, PPM
    NH3, PPM                                   600.        600.        600.        620.        605.
                                                 -           -           -           -           -
    DUST, GRAINS/CU.FT.                     0,0060      0,0060      0,0060      0,0060      0,0060
    TEMPERATURE, F
      WET-BULB                                 105.        105.        106.        106.        105.
      DRY-BULB                                 112.        112.        115.        116.        114.

PERCENT SO2 REMOVAL                           75,81       75,81       75,81       75,80       75,80

MAKEUP LIQUOR TO SCRUBBER
  SULFITE SULFUR, G/L                         56,4        58,4        43,6        46,0        51,1
  BISULFITE SULFUR, G/L                       83,2        82,5        84,5        83,1        83,3
  SULFATE SULFUR, G/L                         11,1         9,8        23,6        22,6        16,8
  PH                                          6,20        6,40        6,20        6,20        6,25
  SPECIFIC GRAVITY                           1,216       1.218       1,218       1.218       1,218
  FORWARD FEED, GPM                            3,0         3,0         3,0         3,0         3,0
  PERCENT FORWARD FLOW TO G-3                   6.          6.          6.          6.          6.

RECIRCULATION RATE, GPM
  G-1                                          30.         31.         31.         31.         31.
  G-2                                          18.         18.         18.         18.         18.
  G-3                                          18.         18.         18.         18.         18.

RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS
  G-1 ELEMENT
    SULFITE SULFUR, G/L                       32,0        31,7        41,9        45,3        37,7
    BISULFATE SULFUR, G/L                     99,7       104,1        94,6        95,9        98,6
    SULFATE SULFUR, G/L                       12,0        13,9        20,2        13,5        14,9
    PH                                        5,80        6,10        6,10        5,80        5,95
    SPECIFIC GRAVITY                         1.206       1.212       1,216       1.220       1,214

  G-2 ELEMENT
    SULFITE SULFUR, G/L                       35,2        36,6        41,2        42,8        39,0
    BISULFATE SULFUR, G/L                     83,8        85,1        83,8        81,3        98,6
    SULFATE SULFUR, G/L                       13,7        13,8        12,7        15,8        14,0
    PH                                        6,00        6,00        6,20        6,00        6,05
    SPECIFIC GRAVITY                         1,190       1.194       1,196       1,196        ,194

  G-3 ELEMENT
    SULFITE SULFUR, G/L                       16,6        18,7        21,2        21,9        19,6
    BISULFATE SULFUR, G/L                     60,9        63,5        63,5        64,1        63,0
    SULFATE SULFUR, G/L                        8,3         8,6        10,1        10,8         9,4
    PH                                        6,00        5,80        5,90        5,90        5,90
    SPECIFIC GRAVITY                         1.126       1.132       1,136       1.140       1,133

RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS
  G-1 ELEMENT
    SULFITE SULFUR, G/L                       31,8        33,6        31,1        37,7        33,5
    BISULFATE SULFUR, G/L                    102,2       106,0       109,2       108,6       106,5
    SULFATE SULFUR, G/L                       13,7        13,1         3,4        13,4        10,9
    PH                                        5,80        5,80        6,10        5,80        5,88
    SPECIFIC GRAVITY                         1,206       1.214       1,220       1,222       1,216

  G-2 ELEMENT
    SULFITE SULFUR, G/L                       33,6        36,4        38,1        41,2        37,3
    BISULFATE SULFUR, G/L                     85,7        87,0        87,6        87,0        86,8
    SULFATE SULFUR, G/L                       17,4        15,3        14,0        12,5        14,8
    PH                                        6,00        6,20        6,00        6,00        6,05
    SPECIFIC GRAVITY                         1,192       1.194       1,198       1,196       1,195

  G-3 ELEMENT
    SULFITE SULFUR, G/L                       17,1        18,7        20,3        21,3        19,3
    BISULFATE SULFUR, G/L                     61,6        64,1        66,7        67,3        64,9
    SULFATE SULFUR, G/L                       10,1        10,0        11,8         9,2        10,3
    PH                                        6,10        5,80        5,80        6,20        5,98
    SPECIFIC GRAVITY                         1,126       1.134       1,140       1,142       1,136
PRODUCT LIQUOR FROM SCRUBBER
  SULFITE SULFUR, G/L                         27,6        31,0        33,9        32,4        31,2
  BISULFITE SULFUR, G/L                      100,9       104,8       105,4       107,9       104,7
  SULFATE SULFUR, G/L                         16,2        13,9        12,4        11,4        13,5
  PH                                          6,10        6,10        5,80        5,90        5,98
  SPECIFIC GRAVITY                           1,204       1.216       1,216       1,220       1,214
  PRODUCT BLEEDOFF, GPM                        3,6         3,6         3,6         3,6         3,6
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AMMONIA ABSORPTION PILOT PLANT TEST NO.RST-1A ,2-26-71

	SAMPLE PERIOD A	B	C	D	MEAN
GAS TO SCRUBBER					
FLOW RATE, CFM AT 120 F	3016.	3016.	2912.	3016.	2990.
TEMPERATURE, F	210.0	214.0	216.0	217.0	214.2
DUST, GRAINS/CU.FT., DRY BASIS	7.8035	7.8035	7.8035	7.8035	7.8035
SO2, PPM	2520.	2520.	2480.	2480.	2500.
EXCESS AIR, PERCENT OXYGEN	5.	5.	5.	5.	5.
GAS FROM SCRUBBER					
G-1 ELEMENT					
SO2, PPM	1160.	1160.	1160.	1160.	1160.
G-2 ELEMENT					
SO2, PPM	530.	530.	510.	510.	520.
G-3 ELEMENT					
SO2, PPM	410.	410.	400.	400.	405.
NH3, PPM	-	-	-	-	-
DUST, GRAINS/CU.FT.	0.0053	0.0053	0.0053	0.0053	0.0053
TEMPERATURE, F					
WET-BULB	108.	108.	109.	109.	109.
DRY-BULB	109.	108.	109.	109.	109.
PERCENT SO2 REMOVAL	83.73	83.73	83.87	83.87	83.80
MAKEUP LIQUOR TO SCRUBBER					
SULFITE SULFUR, G/L	43.6	46.0	56.4	58.4	51.1
BISULFITE SULFUR, G/L	84.5	83.1	83.2	82.5	83.3
SULFATE SULFUR, G/L	23.6	22.6	11.1	9.8	16.8
PH	6.20	6.20	6.20	6.40	6.25
SPECIFIC GRAVITY	1.218	1.218	1.216	1.218	1.218
FOWARD FEED, GPM	5.0	5.0	5.0	5.0	5.0
PERCENT FOWARD FLOW TO G-3	12.	12.	12.	12.	12.
RECIRCULATION RATE, GPM					
G-1	30.	29.	29.	29.	29.
G-2	18.	18.	18.	18.	18.
G-3	18.	18.	18.	18.	18.
RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	41.6	41.6	35.6	37.5	39.1
BISULFATE SULFUR, G/L	98.4	98.4	101.2	98.6	99.1
SULFATE SULFUR, G/L	15.7	15.7	17.9	16.6	16.5
PH	5.90	6.00	5.90	6.00	5.95
SPECIFIC GRAVITY	1.216	1.216	1.218	1.214	1.216
G-2 ELEMENT					
SULFITE SULFUR, G/L	44.4	40.3	40.1	41.2	41.5
BISULFATE SULFUR, G/L	83.2	85.1	83.2	82.5	99.1
SULFATE SULFUR, G/L	12.1	15.[illegible]	17.4	17.0	15.5
PH	6.30	6.10	6.10	6.10	6.15
SPECIFIC GRAVITY	1.196	1.200	1.196	1.198	1.198
G-3 ELEMENT					
SULFITE SULFUR, G/L	28.5	28.9	23.3	27.5	27.1
BISULFATE SULFUR, G/L	63.5	63.5	63.2	61.9	63.0
SULFATE SULFUR, G/L	11.8	10.4	17.3	15.4	13.7
PH	6.00	6.10	6.00	6.10	6.05
SPECIFIC GRAVITY	1.150	1.150	1.151	1.152	1.151
RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	38.5	37.0	30.6	34.9	35.3
BISULFATE SULFUR, G/L	106.2	105.5	106.6	106.6	106.2
SULFATE SULFUR, G/L	16.0	17.2	25.5	19.2	19.5
PH	5.90	5.90	6.00	5.90	5.93
SPECIFIC GRAVITY	1.222	1.222	1.222	1.222	1.222
G-2 ELEMENT					
SULFITE SULFUR, G/L	40.8	42.4	35.2	40.2	39.6
BISULFATE SULFUR, G/L	83.0	83.0	84.5	83.2	83.4
SULFATE SULFUR, G/L	19.9	15.3	21.0	17.3	17.4
PH	6.10	6.20	6.10	6.10	6.12
SPECIFIC GRAVITY	1.196	1.198	1.198	1.196	1.197
G-3 ELEMENT					
SULFITE SULFUR, G/L	28.9	31.2	24.0	31.1	28.8
BISULFATE SULFUR, G/L	64.7	64.7	64.8	65.4	64.9
SULFATE SULFUR, G/L	11.2	9.9	16.0	8.3	11.3
PH	6.10	6.00	6.00	6.00	6.03
SPECIFIC GRAVITY	1.152	1.152	1.152	1.153	1.152
PRODUCT LIQUOR FROM SCRUBBER					
SULFITE SULFUR, G/L	32.4	34.3	35.2	32.4	33.6
BISULFITE SULFUR, G/L	99.9	98.6	97.4	98.0	98.5
SULFATE SULFUR, G/L	22.4	21.8	22.1	24.3	22.7
PH	5.90	6.00	6.00	6.00	5.98
SPECIFIC GRAVITY	1.216	1.216	1.216	1.220	1.217
PRODUCT BLEEDOFF, GPM	5.7	5.7	5.7	5.7	5.7

AMMONIA ABSORPTION PILOT PLANT TEST NO.SST-1   7-7-71

SAMPLE PERIOD	A	B	C	D	E
GAS TO SCRUBBER					
FLOW RATE, CFM AT 120 F	2800.	2800.	2800.	2800.	2800.
TEMPERATURE, F	269.0	275.7	279.3	280.7	282.7
DUST, GRAINS/CU.FT.,DRY BASIS	-	0.3177	0.3177	-	-
SO2, PPM	2860.	2860.	2840.	2860.	2880.
EXCESS AIR, PERCENT OXYGEN	3.	3.	3.	3.	3.
GAS FROM SCRUBBER					
G-1 ELEMENT					
SO2, PPM	-	-	-	-	-
G-2 ELEMENT					
SO2, PPM	-	1340.	-	-	-
G-3 ELEMENT					
SO2, PPM	120.	250.	550.	850.	1200.
NH3, PPM	16.0000	7.0000	11.0000	-	9.0000
DUST, GRAINS/CU.FT.	0.0055	-	-	-	-
TEMPERATURE, F					
WET-BULB	125.	123.	122.	121.	120.
DRY-BULB	125.	124.	123.	122.	119.
PERCENT SO2 REMOVAL	95.80	91.26	80.63	70.28	58.33
MAKEUP LIQUOR TO SCRUBBER					
SULFITE SULFUR, G/L	20.1	27.9	25.5	-	21.2
BISULFITE SULFUR, G/L	61.1	46.1	52.6	57.5	59.9
SULFATE SULFUR, G/L	40.3	42.9	38.1	52.3	41.9
PH	5.55	5.79	5.79	5.70	5.60
SPECIFIC GRAVITY	1.190	1.180	1.180	1.190	1.190
FORWARD FEED, GPM	6.1	6.9	6.4	6.0	6.0
PERCENT FORWARD FLOW TO G-3	10.	10.	10.	10.	10.
RECIRCULATION RATE, GPM					
G-1	26.	26.	26.	26.	26.
G-2	21.	21.	21.	21.	21.
G-3	18.	18.	18.	16.	11.
RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	21.6	18.3	15.7	16.4	15.0
BISULFATE SULFUR, G/L	58.7	66.6	69.3	73.5	73.2
SULFATE SULFUR, G/L	42.3	43.7	40.4	40.3	38.8
PH	5.60	5.47	5.40	5.40	5.35
SPECIFIC GRAVITY	1.190	1.190	1.190	1.200	1.200
G-2 ELEMENT					
SULFITE SULFUR, G/L	23.8	20.4	18.3	15.7	14.3
BISULFATE SULFUR, G/L	40.5	50.4	53.6	59.1	59.6
SULFATE SULFUR, G/L	37.1	37.8	34.5	35.8	37.4
PH	5.82	5.63	5.60	5.50	5.58
SPECIFIC GRAVITY	1.160	1.170	1.170	1.170	1.170
G-3 ELEMENT					
SULFITE SULFUR, G/L	15.0	12.9	14.7	8.7	4.0
BISULFATE SULFUR, G/L	25.4	34.4	42.5	44.8	40.9
SULFATE SULFUR, G/L	23.6	26.4	28.1	26.4	24.0
PH	5.90	5.70	5.70	5.40	5.35
SPECIFIC GRAVITY	1.110	1.120	1.140	1.120	1.110
RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	19.6	17.5	15.9	16.2	16.8
BISULFATE SULFUR, G/L	65.3	71.9	74.8	77.6	77.3
SULFATE SULFUR, G/L	45.3	45.5	40.7	41.2	40.3
PH	5.48	5.40	5.40	5.35	5.32
SPECIFIC GRAVITY	1.190	1.200	1.200	1.200	1.200
G-2 ELEMENT					
SULFITE SULFUR, G/L	23.8	20.4	18.3	15.7	14.3
BISULFATE SULFUR, G/L	40.5	50.4	53.6	59.1	59.6
SULFATE SULFUR, G/L	37.1	37.8	34.5	35.8	37.4
PH	5.82	5.63	5.60	5.50	5.58
SPECIFIC GRAVITY	1.160	1.170	1.170	1.170	1.170
G-3 ELEMENT					
SULFITE SULFUR, G/L	11.2	12.4	12.6	9.9	4.8
BISULFATE SULFUR, G/L	27.5	36.3	43.8	5.7	42.7
SULFATE SULFUR, G/L	26.7	27.2	26.7	24.1	23.0
PH	5.78	5.65	5.60	5.45	5.32
SPECIFIC GRAVITY	1.110	1.120	1.130	1.120	1.110
PRODUCT LIQUOR FROM SCRUBBER					
SULFITE SULFUR, G/L	31.2	18.3	16.9	16.9	13.9
BISULFITE SULFUR, G/L	39.6	67.4	69.4	74.5	73.8
SULFATE SULFUR, G/L	39.4	40.2	38.6	39.6	42.3
PH	5.95	5.43	5.45	5.40	5.35
SPECIFIC GRAVITY	1.180	1.190	1.190	1.200	1.200
PRODUCT BLEEDOFF, GPM	4.79	4.83	4.74	4.82	4.75

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                AMMONIA ABSORPTION PILOT PLANT TEST NO.SST-2   ,7-8-71

      SAMPLE PERIOD
      GAS TO SCRUBBER                                                      A            B           C
        FLOW RATE, CFM AT 125 F
        TEMPERATURE, F                                                 2700.        2680.       2680.
        DUST, GRAINS/CU.FT.,DRY BASIS                                  224.0        224.0       214.0
        SO2, PPM                                                           -            -      0.3254
        EXCESS AIR, PERCENT OXYGEN                                     3070.        3020.       2940.
                                                                          3.           3.          3.

      GAS FROM SCRUBBER
        G-1 ELEMENT
          SO2, PPM

        G-2 ELEMENT                                                        -        1920.           -
          SO2, PPM

        G-3 ELEMENT                                                        -            -           -
          SO2, PPM
          NH3, PPM                                                      462.         685.       1240.
          DUST, GRAINS/CU.FT.                                         5.0000       4.0000      3.0000
          TEMPERATURE, F                                              0.0075       0.0075      0.0000
            WET-BULB
            DRY-BULB                                                    119.         119.        119.
                                                                        120.         119.        118.

      PERCENT SO2 REMOVAL
                                                                       84.95        77.32       57.82

      MAKEUP LIQUOR TO SCRUBBER
        SULFITE SULFUR, G/L
        BISULFITE SULFUR, G/L                                           34.9         30.9        27.8
        SULFATE SULFUR, G/L                                              0.0          9.5        14.7
        PH                                                               9.5          6.6         7.5
        SPECIFIC GRAVITY                                                7.42         6.80        6.60
        FORWARD FEED, GPM                                              1.080        1.090       1.090
        PERCENT FORWARD FLOW TO G-3                                      1.4          1.5         1.4
                                                                         10.          10.         10.

      RECIRCULATION RATE, GPM
        G-1
        G-2                                                              28.          28.         28.
        G-3                                                              22.          22.         22.
                                                                         18.          18.         18.

      RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS
        G-1 ELEMENT
          SULFITE SULFUR, G/L
          BISULFATE SULFUR, G/L                                          2.8          5.6         3.8
          SULFATE SULFUR, G/L                                           54.4         54.1        54.8
          PH                                                            11.5          9.8        11.2
          SPECIFIC GRAVITY                                              5.10         5.10        5.15
                                                                       1.100        1.100       1.100
        G-2 ELEMENT
          SULFITE SULFUR, G/L
          BISULFATE SULFUR, G/L                                          8.6          9.6         5.4
          SULFATE SULFUR, G/L                                           31.7         35.2        39.4
          PH                                                             9.1          6.4         3.2
          SPECIFIC GRAVITY                                              5.78         5.65        5.40
                                                                       1.070        1.080       1.080
        G-3 ELEMENT
          SULFITE SULFUR, G/L
          BISULFATE SULFUR, G/L                                         -0.5          4.8         0.0
          SULFATE SULFUR, G/L                                           20.1         21.8        22.3
          PH                                                             7.3          4.5         6.8
          SPECIFIC GRAVITY                                              5.12         5.35        3.10
                                                                       1.040        1.040       1.040

      RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS
        G-1 ELEMENT
          SULFITE SULFUR, G/L
          BISULFATE SULFUR, G/L                                          2.6          4.5         4.5
          SULFATE SULFUR, G/L                                           56.9         55.5        57.5
          PH                                                            11.1         12.1         7.8
          SPECIFIC GRAVITY                                              5.00         5.10        5.00
                                                                       1.100        1.100       1.100
        G-2 ELEMENT
          SULFITE SULFUR, G/L
          BISULFATE SULFUR, G/L                                          8.6          9.6         5.4
          SULFATE SULFUR, G/L                                           31.7         35.2        39.4
          PH                                                             9.1          6.4         3.2
          SPECIFIC GRAVITY                                              5.78         5.65        5.40
                                                                       1.070        1.080       1.080
        G-3 ELEMENT
          SULFITE SULFUR, G/L
          BISULFATE SULFUR, G/L                                          0.7          1.7         0.8
          SULFATE SULFUR, G/L                                           22.0         21.9        23.9
          PH                                                             6.0          6.5         6.7
          SPECIFIC GRAVITY                                              5.45         3.10        3.65
                                                                       1.040        1.050       1.050

      PRODUCT LIQUOR FROM SCRUBBER
        SULFITE SULFUR, G/L
        BISULFITE SULFUR, G/L                                            4.9          6.3         4.8
        SULFATE SULFUR, G/L                                             52.3         54.8        55.4
        PH                                                               9.0          8.7         9.5
        SPECIFIC GRAVITY                                                5.25         5.25        5.15
        PRODUCT BLEEDOFF, GPM                                          1.090        1.100       1.100
                                                                        0.88         2.17        2.17
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AMMONIA ABSORPTION PILOT PLANT TEST NO.SST-3 ,7-9-71

SAMPLE PERIOD	A	B	C	D	E
GAS TO SCRUBBER					
FLOW RATE, CFM AT 120 F	2700.	2660,	2660,	2660,	2660,
TEMPERATURE, F	225,0	225,0	226,0	229,0	230,0
DUST, GRAINS/CU.FT., DRY BASIS	-	0,2059	0,2059	-	-
SO2, PPM	2840,	2870,	2920,	2960,	2920,
EXCESS AIR, PERCENT OXYGEN	3,	3,	3,	3,	3,
GAS FROM SCRUBBER					
G-1 ELEMENT					
SO2, PPM	-	1200,	1460,	1660,	1980,
G-2 ELEMENT					
SO2, PPM	-	51,	160,	410,	555,
G-3 ELEMENT					
SO2, PPM	35,	25,	65,	190,	365,
NH3, PPM	53,0000	23,0000	2,0000	5,0000	0,0000
DUST, GRAINS/CU.FT.	0,0079	0,0000	0,0000	0,0000	0,0000
TEMPERATURE, F					
WET-BULB	119,	119,	119,	119,	121,
DRY-BULB	119,	119,	119,	119,	120,
PERCENT SO2 REMOVAL	98,77	99,13	97,77	93,58	87,50
MAKEUP LIQUOR TO SCRUBBER					
SULFITE SULFUR, G/L	50,2	49,5	48,8	44,7	39,2
BISULFITE SULFUR, G/L	16.1	19,6	23,1	26,5	33,7
SULFATE SULFUR, G/L	8,0	8,4	8,8	8,5	10,6
PH	6,80	6,65	6,40	6,50	6,25
SPECIFIC GRAVITY	1.130	1.120	1.130	1.130	1,130
FORWARD FEED, GPM	2,0	2,0	2,0	2,0	2,1
PERCENT FORWARD FLOW TO G-3	20,	20,	20,	20,	20,
RECIRCULATION RATE, GPM					
G-1	27,	27,	28,	28,	27,
G-2	24,	25,	25,	26,	26,
G-3	12,	12,	11,	11,	11,
RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	16.3	14,8	18,4	16,4	13,8
BISULFATE SULFUR, G/L	61,4	68,6	72,5	77,3	79,1
SULFATE SULFUR, G/L	8,8	14,1	10,9	11,2	7,6
PH	5,60	5,60	5,60	5,50	5,38
SPECIFIC GRAVITY	1.120	1.140	1.150	1.150	1.150
G-2 ELEMENT					
SULFITE SULFUR, G/L	27,5	26,7	26,4	22,4	15,7
BISULFATE SULFUR, G/L	24,8	35,0	36,9	46,7	50,8
SULFATE SULFUR, G/L	7,7	8,5	8,1	8,0	10,0
PH	6,30	6,10	6,10	5,95	5,70
SPECIFIC GRAVITY	1,090	1.110	1.110	1.110	1.120
G-3 ELEMENT					
SULFITE SULFUR, G/L	16,7	16,0	17,9	14,4	8,8
BISULFATE SULFUR, G/L	14,4	18,3	22,1	27,5	32,3
SULFATE SULFUR, G/L	5,0	6,0	5,2	6,0	8,3
PH	6,45	6,25	6,35	6,00	5,75
SPECIFIC GRAVITY	1.060	1.070	1,080	1.070	1,080
RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	11,7	11,3	17,8	15,8	12,3
BISULFATE SULFUR, G/L	66,0	74,5	78,4	82,2	84,7
SULFATE SULFUR, G/L	11,3	15,4	11,3	11,1	10,9
PH	5,50	5,50	5,55	5,40	5,32
SPECIFIC GRAVITY	1.120	1.140	1.150	1.150	1.150
G-2 ELEMENT					
SULFITE SULFUR, G/L	27,5	26,7	26,4	22,4	15,7
BISULFATE SULFUR, G/L	24,8	35,0	36,9	46,7	50,8
SULFATE SULFUR, G/L	7,7	8,5	8,1	8,0	10,0
PH	6,30	6,10	6,10	5,95	5,70
SPECIFIC GRAVITY	1,090	1.110	1.110	1.110	1.120
G-3 ELEMENT					
SULFITE SULFUR, G/L	16,3	17,2	14,4	14,6	9,1
BISULFATE SULFUR, G/L	14,4	19,6	24,1	29,1	34,3
SULFATE SULFUR, G/L	5,4	6,3	8,6	5,5	7,0
PH	6,40	6,30	6,10	5,95	5,75
SPECIFIC GRAVITY	1,060	1,070	1,080	1,080	1,080
PRODUCT LIQUOR FROM SCRUBBER					
SULFITE SULFUR, G/L	18,5	12,0	19,4	17,0	14,4
BISULFITE SULFUR, G/L	63,7	70,6	73,9	78,3	81,0
SULFATE SULFUR, G/L	8,0	16,4	9,9	10,3	10,5
PH	5,60	5,60	5,60	5,55	5,38
SPECIFIC GRAVITY	1.130	1.140	1.150	1.140	1.150
PRODUCT BLEEDOFF, GPM	1,97	2,03	2,08	2,09	1,97

AMMONIA ABSORPTION PILOT PLANT TEST NO.SST-4 ,7-12-71

SAMPLE PERIOD	A	B	C	D	E
GAS TO SCRUBBER					
FLOW RATE, CFM AT 120 F	2800.	2800.	2800.	2800.	2800.
TEMPERATURE, F	259,0	265.0	269,0	272.0	277,0
DUST, GRAINS/CU.FT., DRY BASIS	0,5869	0,0000	0,0000	0,0000	0,0000
SO2, PPM	2800.	2760.	2760.	2800.	2800.
EXCESS AIR, PERCENT OXYGEN	4.	3.	3.	3.	3.
GAS FROM SCRUBBER					
G-1 ELEMENT					
SO2, PPM	140.	0.	0.	0.	290.
G-2 ELEMENT					
SO2, PPM	190.	0.	0.	0.	0.
G-3 ELEMENT					
SO2, PPM	85.	180.	140.	140.	0.
NH3, PPM	585,0000	364,0000	278,0000	189,0000	158,0000
DUST, GRAINS/CU.FT.	0,0622	0,0000	0,0000	0,1106	0,0000
TEMPERATURE, F					
WET-BULB	119.	120.	119.	119.	119.
DRY-BULB	119.	120.	119.	120.	121.
PERCENT SO2 REMOVAL	96,96	93,48	94,93	95,00	100,00
MAKEUP LIQUOR TO SCRUBBER					
SULFITE SULFUR, G/L	46,3	44,5	42,8	40,2	36,4
BISULFITE SULFUR, G/L	16,2	22,9	27,9	32,5	38,3
SULFATE SULFUR, G/L	10,3	8,7	7,3	8,3	7,8
PH	6,71	6,50	6,40	6,25	6,15
SPECIFIC GRAVITY	1.120	1.120	1.130	1.130	1.130
FORWARD FEED, GPM	6,8	6,8	6,6	6,5	6,7
PERCENT FORWARD FLOW TO G-3	20.	20.	20.	20.	20.
RECIRCULATION RATE, GPM					
G-1	30.	30.	31.	31.	26.
G-2	27.	27.	27.	28.	28.
G-3	18.	18.	18.	18.	18.
RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	30.1	35.2	29.0	30.3	24.8
BISULFATE SULFUR, G/L	36.9	38.2	44.8	45.6	49.7
SULFATE SULFUR, G/L	11.0	9.0	11.9	9.7	12.4
PH	6.12	6.15	6.00	6.00	5.85
SPECIFIC GRAVITY	1.120	1.130	1.130	1.130	1.130
G-2 ELEMENT					
SULFITE SULFUR, G/L	36.7	37.8	33.9	30.9	30.9
BISULFATE SULFUR, G/L	16.7	20.7	25.0	29.2	33.5
SULFATE SULFUR, G/L	11.0	8.2	9.7	10.5	7.3
PH	6.60	6.50	6.30	6.25	6.15
SPECIFIC GRAVITY	1.110	1.110	1.110	1.120	1.110
G-3 ELEMENT					
SULFITE SULFUR, G/L	28.0	29.1	25.5	20.8	22.4
BISULFATE SULFUR, G/L	11.0	14.4	17.5	23.9	25.8
SULFATE SULFUR, G/L	7.7	5.2	7.0	6.5	6.3
PH	6.71	6.60	6.40	6.35	6.20
SPECIFIC GRAVITY	1.080	1.090	1.080	1.080	1.090
RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	31.9	33.3	27.1	24.5	24.7
BISULFATE SULFUR, G/L	40.2	44.5	50.5	52.6	56.2
SULFATE SULFUR, G/L	12.5	9.2	11.9	13.9	10.2
PH	6.10	6.05	5.95	5.90	5.80
SPECIFIC GRAVITY	1.130	1.130	1.130	1.140	1.140
G-2 ELEMENT					
SULFITE SULFUR, G/L	36.7	37.8	33.9	30.9	30.9
BISULFATE SULFUR, G/L	16.7	20.7	25.0	29.2	33.5
SULFATE SULFUR, G/L	11.0	8.2	9.7	10.5	7.3
PH	6.60	6.50	6.30	6.25	6.15
SPECIFIC GRAVITY	1.110	1.110	1.110	1.120	1.110
G-3 ELEMENT					
SULFITE SULFUR, G/L	26.5	29.1	25.9	24.5	21.5
BISULFATE SULFUR, G/L	11.1	14.4	18.6	21.9	26.5
SULFATE SULFUR, G/L	9.6	5.5	6.1	5.9	6.9
PH	6.70	6.50	6.40	6.30	6.10
SPECIFIC GRAVITY	1.080	1.080	1.080	1.090	1.080
PRODUCT LIQUOR FROM SCRUBBER					
SULFITE SULFUR, G/L	36.5	31.1	29.4	26.7	26.1
BISULFITE SULFUR, G/L	34.3	40.1	45.6	49.2	52.5
SULFATE SULFUR, G/L	6.7	11.9	10.8	11.0	10.5
PH	6.24	6.15	6.00	5.95	5.90
SPECIFIC GRAVITY	1.120	1.130	1.130	1.130	1.140
PRODUCT BLEED-OFF, GPM	5.68	5.90	5.14	4.86	6.66

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     AMMONIA ABSORPTION PILOT PLANT TEST NO.SST-5   ,7-13-71

  SAMPLE PERIOD
  GAS TO SCRUBBER                                      A          B           C           D
    FLOW RATE, CFM AT 120 F
    TEMPERATURE, F                                 2500.      2500.       2500.       2500.
    DUST, GRAINS/CU.FT.,DRY BASIS                  227.0      226.0       227.0       222.0
    SO2, PPM                                      0.2075         -           -           -
    EXCESS AIR, PERCENT OXYGEN                     2700.      2730.       2720.       2720.
                                                      3.         3.          3.          3.
  GAS FROM SCRUBBER
    G-1 ELEMENT
      SO2, PPM
                                                      -      1360.       1435.       1920.
    G-2 ELEMENT
      SO2, PPM
                                                      -       475.        685.        790.
    G-3 ELEMENT
      SO2, PPM
      NH3, PPM                                        -       440.        580.        686.
      DUST, GRAINS/CU.FT.                         9.0000     6.0000          -       5.0000
      TEMPERATURE, F                              0.0753     0.0893      0.0893      0.0893
        WET-BULB
        DRY-BULB                                    117.       116.        117.        118.
                                                    118.       118.        119.        119.
  PERCENT SO2 REMOVAL
                                                      -      83.88       78.68       74.78
  MAKEUP LIQUOR TO SCRUBBER
    SULFITE SULFUR, G/L
    BISULFITE SULFUR, G/L                           40.4       39.5        35.6        33.0
    SULFATE SULFUR, G/L                             20.0       23.2        29.7        33.2
    PH                                              38.3       38.6        37.4        37.6
    SPECIFIC GRAVITY                                6.45       6.35        6.17        6.07
    FORWARD FEED, GPM                              1.170      1.167       1.168       1.167
    PERCENT FORWARD FLOW TO G-3                      2.0        1.9         1.9         1.5
                                                     10.        10.         10.         10.
  RECIRCULATION RATE, GPM
    G-1
    G-2                                              27.        27.         27.         26.
    G-3                                              26.        26.         26.         26.
                                                     18.        18.         18.         18.
  RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS
    G-1 ELEMENT
      SULFITE SULFUR, G/L
      BISULFATE SULFUR, G/L                          8.8       12.7        12.7        10.7
      SULFATE SULFUR, G/L                           62.6       68.8        71.0        70.6
      PH                                            37.2       37.9        38.2        39.4
      SPECIFIC GRAVITY                              5.22       5.30        5.30        5.22
                                                   1.170      1.180       1.184       1.178
    G-2 ELEMENT
      SULFITE SULFUR  G/L
      BISULFATE SULFUR, G/L                         16.3       16.0        12.3        11.0
      SULFATE SULFUR, G/L                           40.9       44.8        48.5        49.8
      PH                                            30.8       31.9        32.9        32.7
      SPECIFIC GRAVITY                              5.72       5.57        5.43        5.40
                                                   1.140      1.146       1.148       1.147
    G-3 ELEMENT
      SULFITE SULFUR, G/L
      BISULFATE SULFUR, G/L                          7.0        3.8         5.0         5.1
      SULFATE SULFUR, G/L                           27.1       31.3        30.8        31.2
      PH                                            16.9       17.5        17.4        16.3
      SPECIFIC GRAVITY                              5.52       5.08        5.03        5.20
                                                   1.079      1.083       1.084       1.084
  RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS
    G-1 ELEMENT
      SULFITE SULFUR, G/L
      BISULFATE SULFUR, G/L                         10.1       10.6        11.6        10.2
      SULFATE SULFUR, G/L                           68.7       72.5        74.9        72.9
      PH                                            37.2       39.7        38.4        38.3
      SPECIFIC GRAVITY                              5.32       5.22        5.25        5.20
                                                   1.180      1.185       1.187       1.183
    G-2 ELEMENT
      SULFITE SULFUR, G/L
      BISULFATE SULFUR, G/L                         14.6       16.0        13.5        10.5
      SULFATE SULFUR, G/L                           44.0       47.2        51.5        51.7
      PH                                            32.1       29.9        29.8        32.0
      SPECIFIC GRAVITY                              5.67       5.58        5.50        5.33
                                                   1.150      1.147       1.147       1.146
    G-3 ELEMENT
      SULFITE SULFUR, G/L
      BISULFATE SULFUR, G/L                          4.3        5.0         4.7         5.1
      SULFATE SULFUR, G/L                           28.3       30.6        32.4        32.5
      PH                                            17.4       17.8        17.4        16.3
      SPECIFIC GRAVITY                              5.51       5.43        5.32        5.19
                                                   1.080      1.085       1.085       1.084

  PRODUCT LIQUOR FROM SCRUBBER
    SULFITE SULFUR, G/L
    BISULFITE SULFUR, G/L                           10.2       12.8        11.2        11.7
    SULFATE SULFUR, G/L                             62.2       67.2        71.0        69.4
    PH                                              35.6       37.2        38.5        36.4
    SPECIFIC GRAVITY                                5.34       5.33        5.27        5.27
    PRODUCT BLEEDOFF, GPM                          1.170      1.177       1.182       1.178
                                                    2.15       2.13        2.01        2.06
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AMMONIA ABSORPTION PILOT PLANT TEST NO,SST-6 ,7-14-71

SAMPLE PERIOD	A	B	C	D	E	F
GAS TO SCRUBBER						
FLOW RATE, CFM AT 120 F	2650.	2650.	2700.	2750.	2800.	2800
TEMPERATURE, F	267.0	272.0	273.0	275.0	278.0	289.
DUST, GRAINS/CU.FT.,DRY BASIS	0.2228	-	-	-	-	
SO2, PPM	2640.	2680.	2660.	2780.	2720.	2870
EXCESS AIR, PERCENT OXYGEN	3.	3.	3.	3.	3.	3
GAS FROM SCRUBBER						
G-1 ELEMENT						
SO2, PPM	1200.	1280.	-	1720.	1840.	-
G-2 ELEMENT						
SO2, PPM	115.	300.	400.	770.	910.	1240
G-3 ELEMENT						
SO2, PPM	76.	168.	315.	590.	613.	700
NH3, PPM	72.0000	56.0000	-	20.0000	16.0000	13.000
DUST, GRAINS/CU.FT.	0.1845	-	-	-	0.1466	0.146
TEMPERATURE, F						
WET-BULB	121.	120.	120.	120.	120.	121
DRY-BULB	122.	121.	121.	122.	122.	123
PERCENT SO2 REMOVAL	97.12	93.73	88.16	78.78	77.46	75.6
MAKEUP LIQUOR TO SCRUBBER						
SULFITE SULFUR, G/L	54.7	50.9	46.6	44.9	42.7	40.
BISULFITE SULFUR, G/L	11.1	16.6	20.6	26.2	31.1	35.
SULFATE SULFUR, G/L	37.0	36.0	37.7	36.8	36.5	37.
PH	6.80	6.61	6.45	6.30	6.22	6.1
SPECIFIC GRAVITY	1.180	1.180	1.180	1.180	1.190	1.19
FORWARD FEED, GPM	1.7	1.8	1.7	1.5	1.6	1.
PERCENT FORWARD FLOW TO G-3	20.	20.	20.	20.	20.	2
RECIRCULATION RATE, GPM						
G-1	28.	27.	27.	27.	27.	27
G-2	26.	26.	26.	26.	26.	26
G-3	18.	18.	18.	18.	18.	18.
RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS						
G-1 ELEMENT						
SULFITE SULFUR, G/L	14.3	17.7	22.1	21.5	16.6	18.
BISULFATE SULFUR, G/L	48.1	62.1	69.7	73.4	77.1	78.
SULFATE SULFUR, G/L	29.7	36.6	38.8	38.7	41.2	39.4
PH	5.58	5.53	5.50	5.48	5.39	5.4
SPECIFIC GRAVITY	1.150	1.190	1.200	1.200	1.210	1.21
G-2 ELEMENT						
SULFITE SULFUR, G/L	23.8	25.3	25.9	20.7	14.7	16.
BISULFATE SULFUR, G/L	22.9	29.7	37.3	44.6	51.0	53.1
SULFATE SULFUR, G/L	24.3	27.2	25.5	27.9	29.9	28.4
PH	6.15	6.04	5.89	5.79	5.55	5.5
SPECIFIC GRAVITY	1.120	1.140	1.150	1.150	1.160	1.15
G-3 ELEMENT						
SULFITE SULFUR, G/L	15.3	16.1	15.0	36.3	9.5	8.
BISULFATE SULFUR, G/L	12.7	18.1	23.4	29.0	32.8	35.
SULFATE SULFUR, G/L	14.0	16.7	17.4	16.6	18.0	17.
PH	6.31	6.15	5.99	5.80	5.64	5.5
SPECIFIC GRAVITY	1.080	1.100	1.100	1.100	1.100	1.10
RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS						
G-1 ELEMENT						
SULFITE SULFUR, G/L	12.2	20.5	20.5	21.6	18.5	17.
BISULFATE SULFUR, G/L	50.5	68.0	74.4	79.6	81.2	82.
SULFATE SULFUR, G/L	29.1	36.4	41.0	38.4	40.3	39.
PH	5.40	5.50	5.44	5.40	5.40	5.3
SPECIFIC GRAVITY	1.180	1.190	1.210	1.210	1.210	1.21
G-2 ELEMENT						
SULFITE SULFUR, G/L	24.3	24.7	23.2	19.1	18.7	15.
BISULFATE SULFUR, G/L	24.7	34.5	40.9	48.3	46.4	55.
SULFATE SULFUR, G/L	24.1	26.8	27.2	26.9	31.4	27.
PH	6.10	5.93	5.85	5.70	5.50	5.48
SPECIFIC GRAVITY	1.120	1.140	1.150	1.150	1.180	1.160
G-3 ELEMENT						
SULFITE SULFUR, G/L	14.7	15.6	14.3	11.6	7.5	7.5
BISULFATE SULFUR, G/L	13.7	20.2	24.9	31.1	34.7	37.
SULFATE SULFUR, G/L	15.2	17.1	17.8	17.4	18.3	18.2
PH	6.25	6.10	5.89	5.74	5.54	5.45
SPECIFIC GRAVITY	1.080	1.090	1.100	1.100	1.090	1.100
PRODUCT LIQUOR FROM SCRUBBER						
SULFITE SULFUR, G/L	18.5	21.8	20.9	20.9	19.3	17.0
BISULFITE SULFUR, G/L	52.2	63.1	70.0	74.3	76.8	79.9
SULFATE SULFUR, G/L	31.2	35.8	39.4	38.7	39.0	39.2
PH	5.55	5.55	5.54	5.50	5.40	5.38
SPECIFIC GRAVITY	1.170	1.200	1.200	1.210	1.200	1.210
PRODUCT BLEEDOFF, GPM	1.95	1.90	1.89	1.67	1.83	1.79

AMMONIA ABSORPTION PILOT PLANT TEST NO.SST-7 ,7-15-71

SAMPLE PERIOD	A	B	C	D
GAS TO SCRUBBER				
FLOW RATE, CFM AT 120 F	2600.	2600.	2620.	2620.
TEMPERATURE, F	265.0	267.0	269.0	271.0
DUST, GRAINS/CU.FT., DRY BASIS	0.4391	-	-	-
SO2, PPM	2680.	2670.	2790.	2800.
EXCESS AIR, PERCENT OXYGEN	3.	3.	3.	3.
GAS FROM SCRUBBER				
G-1 ELEMENT				
SO2, PPM	2060.	2180.	2220.	2260.
G-2 ELEMENT				
SO2, PPM	1120.	1400.	1500.	1520.
G-3 ELEMENT				
SO2, PPM	1080.	1380.	1500.	1660.
NH3, PPM	37.0000	10.0000	3.0000	8.0000
DUST, GRAINS/CU.FT.	0.0911	-	0.1068	-
TEMPERATURE, F				
WET-BULB	120.	119.	119.	122.
DRY-BULB	121.	119.	120.	122.
PERCENT SO2 REMOVAL	59.70	48.31	46.24	40.71
MAKEUP LIQUOR TO SCRUBBER				
SULFITE SULFUR, G/L	26.4	23.7	23.7	22.2
BISULFITE SULFUR, G/L	4.0	6.9	6.4	10.1
SULFATE SULFUR, G/L	54.6	56.6	55.8	56.2
PH	6.85	6.60	6.50	6.50
SPECIFIC GRAVITY	1.160	1.180	1.160	1.160
FORWARD FEED, GPM	1.4	1.3	1.2	1.2
PERCENT FORWARD FLOW TO G-3	10.	10.	10.	10.
RECIRCULATION RATE, GPM				
G-1	26.	26.	27.	27.
G-2	26.	26.	26.	26.
G-3	18.	18.	18.	18.
RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS				
G-1 ELEMENT				
SULFITE SULFUR, G/L	3.4	4.4	3.2	4.6
BISULFATE SULFUR, G/L	33.9	39.1	45.0	45.4
SULFATE SULFUR, G/L	42.9	49.5	56.0	58.2
PH	5.00	4.99	5.04	5.13
SPECIFIC GRAVITY	1.140	1.160	1.160	1.180
G-2 ELEMENT				
SULFITE SULFUR, G/L	4.6	4.2	1.2	1.7
BISULFATE SULFUR, G/L	24.9	28.5	29.7	30.0
SULFATE SULFUR, G/L	35.1	38.3	40.4	39.9
PH	5.39	5.20	5.03	5.10
SPECIFIC GRAVITY	1.120	1.120	1.120	1.130
G-3 ELEMENT				
SULFITE SULFUR, G/L	1.8	0.8	0.2	0.4
BISULFATE SULFUR, G/L	8.9	13.8	16.2	15.9
SULFATE SULFUR, G/L	14.0	19.9	20.9	21.3
PH	4.60	2.75	5.00	4.73
SPECIFIC GRAVITY	1.050	1.060	1.070	1.070
RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS				
G-1 ELEMENT				
SULFITE SULFUR, G/L	1.9	4.0	-2.6	4.0
BISULFATE SULFUR, G/L	31.0	42.2	49.2	47.8
SULFATE SULFUR, G/L	38.9	50.7	65.7	60.7
PH	4.40	4.91	5.00	5.13
SPECIFIC GRAVITY	1.130	1.160	1.180	1.190
G-2 ELEMENT				
SULFITE SULFUR, G/L	4.4	3.6	2.2	1.5
BISULFATE SULFUR, G/L	23.1	30.2	31.5	31.5
SULFATE SULFUR, G/L	31.2	38.1	38.5	39.2
PH	5.15	5.05	5.12	5.10
SPECIFIC GRAVITY	1.100	1.130	1.130	1.130
G-3 ELEMENT				
SULFITE SULFUR, G/L	0.4	1.2	0.0	0.1
BISULFATE SULFUR, G/L	9.1	16.0	16.6	16.8
SULFATE SULFUR, G/L	16.3	19.3	21.4	21.7
PH	2.65	4.55	4.70	4.70
SPECIFIC GRAVITY	1.050	1.070	1.070	1.070
PRODUCT LIQUOR FROM SCRUBBER				
SULFITE SULFUR, G/L	1.8	2.4	3.7	4.1
BISULFITE SULFUR, G/L	28.8	40.5	45.0	45.3
SULFATE SULFUR, G/L	37.1	51.7	56.5	58.2
PH	4.80	4.84	5.05	5.20
SPECIFIC GRAVITY	1.120	1.160	1.180	1.190
PRODUCT BLEEDOFF, GPM	1.80	1.62	1.44	1.47

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       AMMONIA ABSORPTION PILOT PLANT TEST NO.SST-8   ,7-16-71

SAMPLE PERIOD
GAS TO SCRUBBER                                       A          B          C          D          E          F
  FLOW RATE, CFM AT 120 F
  TEMPERATURE, F                                  2600.      2600.      2600.      2600.      2650.      265
  DUST, GRAINS/CU.FT.,DRY BASIS                   225.0      221.0      223.0      226.0      228.0      228.
  SO2, PPM                                       0.7985          -          -          -          -
  EXCESS AIR, PERCENT OXYGEN                      2720.      2760.      2760.      2740.      2720.      272
                                                     3.         3.         3.         4.         3.

GAS FROM SCRUBBER
  G-1 ELEMENT
    SO2, PPM
                                                      -          -      1020.      1220.      1520.      182
  G-2 ELEMENT
    SO2, PPM
                                                      -        85.       202.          -       570.      80
  G-3 ELEMENT
    SO2, PPM
    NH3, PPM                                         0.        31.        58.       270.       578.      86
    DUST, GRAINS/CU.FT.                        193.0000   156.0000     6.0000    15.0000     7.0000    4.00
    TEMPERATURE, F                               0.0000     0.3210     0.1242     0.1242          -
      WET-BULB
      DRY-BULB                                     118.       117.       117.       118.       116.      11
                                                   119.       117.       117.       118.       118.      11

PERCENT SO2 REMOVAL                              100.00      98.86      97.90      90.15      78.86      68.

MAKEUP LIQUOR TO SCRUBBER
  SULFITE SULFUR, G/L
  BISULFITE SULFUR, G/L                            28.1       24.7       21.3       19.1       16.2      13.
  SULFATE SULFUR, G/L                               3.6        8.4       13.8       19.1       24.4      27.
  PH                                               61.4       61.9       62.2       70.0       62.0      62.
  SPECIFIC GRAVITY                                 6.99       6.53       6.25       6.00       5.86      5.
  FORWARD FEED, GPM                               1.180      1.180      1.180      1.100      1.180     1.1
  PERCENT FORWARD FLOW TO G-3                       5.6        5.5        5.2        5.3        5.5      0.
                                                    10.        10.        10.        10.        10.

RECIRCULATION RATE, GPM
  G-1
  G-2                                               25.        25.        25.        25.        25.      2
  G-3                                               25.        26.        26.        26.         0.
                                                    18.        18.        18.        18.        18.      1

RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS
  G-1 ELEMENT
    SULFITE SULFUR, G/L
    BISULFATE SULFUR, G/L                           9.7       12.4        8.4        8.5        7.3      6.
    SULFATE SULFUR, G/L                            24.3       29.1       36.5       40.3       41.2      43.
    PH                                             52.1       61.9       62.4       62.1       63.0      62.
    SPECIFIC GRAVITY                               5.66       5.63       5.55       5.32       5.35      5.
                                                  1.160      1.180      1.190      1.190      1.190     1.1

  G-2 ELEMENT
    SULFITE SULFUR, G/L
    BISULFATE SULFUR, G/L                          18.8       17.7       13.9       12.8       10.5      8.
    SULFATE SULFUR, G/L                             7.8       14.5       19.1       25.3       29.4      33.
    PH                                             50.4       55.8       58.1       57.2       56.7      56.
    SPECIFIC GRAVITY                               6.43       6.15       5.98       5.72       5.65      5.
                                                  1.150      1.160      1.170      1.170      1.170     1.1

  G-3 ELEMENT
    SULFITE SULFUR, G/L
    BISULFATE SULFUR, G/L                           9.6       11.4        9.8        7.0        4.1      2
    SULFATE SULFUR, G/L                             4.7        9.1       14.1       20.5       25.2      27
    PH                                             28.5       38.0       38.3       39.0       38.9      39
    SPECIFIC GRAVITY                               6.57       6.28       5.99       5.68       5.45      5.
                                                  1.090      1.010      1.120      1.120      1.120     1.1

RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS
  G-1 ELEMENT
    SULFITE SULFUR, G/L
    BISULFATE SULFUR, G/L                           9.2       10.3        8.1        7.0        5.9      5
    SULFATE SULFUR, G/L                            31.7       39.2       40.8       44.3       46.1      47
    PH                                             56.6       62.0       63.6       64.4       64.0      64
    SPECIFIC GRAVITY                               5.51       5.50       5.33       5.25       5.20      5.
                                                  1.170      1.190      1.200      1.200      1.200     1.2

  G-2 ELEMENT
    SULFITE SULFUR, G/L
    BISULFATE SULFUR, G/L                          18.2       18.0       14.2       10.5        8.8      7
    SULFATE SULFUR, G/L                            10.5       13.8       22.5       29.5       33.7      35
    PH                                             52.9       55.8       56.5       57.1       56.4      57
    SPECIFIC GRAVITY                               6.30       6.15       5.85       5.61       5.49      5.
                                                  1.150      1.160      1.170      1.170      1.170     1.1

  G-3 ELEMENT
    SULFITE SULFUR, G/L
    BISULFATE SULFUR, G/L                           9.6       11.1        8.3        6.1        3.2      3
    SULFATE SULFUR, G/L                             4.7       10.0       15.8       22.2       26.0      28
    PH                                             28.7       38.3       39.4       39.3       40.1      39
    SPECIFIC GRAVITY                               6.93       6.22       5.64       5.60       5.34      5.
                                                  1.100      1.110      1.120      1.120      1.130     1.1


PRODUCT LIQUOR FROM SCRUBBER
  SULFITE SULFUR, G/L
  BISULFITE SULFUR, G/L                            12.7       12.3       10.1        8.7        6.9      6
  SULFATE SULFUR, G/L                              24.4       30.6       36.1       39.6       42.4      44
  PH                                               54.9       61.2       63.2       62.8       62.8      62
  SPECIFIC GRAVITY                                 5.76       5.68       5.50       5.39       5.32      5.
  PRODUCT RUNOFF, GPM                             1.170      1.190      1.190      1.190      1.190     1.1
                                                   5.31       5.08       4.88       4.91       5.16      0.
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AMMONIA ABSORPTION PILOT PLANT TEST NO.SST-9 ,7-28-71

SAMPLE PERIOD	A	B	C	D	E	F	G	H	I
GAS TO SCRUBBER									
FLOW RATE, CFM AT 120 F	2650.	2700.	2700.	2700.	2700.	2700.	2700.	2700.	2700.
TEMPERATURE, F	206.0	215.0	219.0	219.6	218.0	222.0	225.0	227.0	229.0
DUST, GRAINS/CU.FT.,DRY BASIS	-	-	-	-	-	-	0.0121	0.0121	0.0121
SO2, PPM	2620.	2600.	2600.	2600.	2600.	2540.	2600.	2560.	2560.
EXCESS AIR, PERCENT OXYGEN	4.	3.	2.	2.	3.	4.	4.	4.	4.
GAS FROM SCRUBBER									
G-1 ELEMENT									
SO2, PPM	250.	235.	270.	-	370.	1000.	1040.	1200.	1400.
G-2 ELEMENT									
SO2, PPM	18.	50.	-	-	30.	-	580.	640.	750.
G-3 ELEMENT									
SO2, PPM	23.	68.	27.	44.	30.	220.	340.	470.	665.
NH3, PPM	-	-	-	-	-	-	-	4.0000	4.0000
DUST, GRAINS/CU.FT.	-	-	-	-	-	-	-	-	0.0925
TEMPERATURE, F									
WET-BULB	111.	112.	113.	114.	115.	115.	114.	115.	115.
DRY-BULB	112.	113.	114.	114.	114.	115.	115.	116.	116.
PERCENT SO2 REMOVAL	99.12	97.36	98.96	98.23	98.85	91.02	86.92	81.64	74.02
MAKEUP LIQUOR TO SCRUBBER									
SULFITE SULFUR, G/L	55.9	50.5	48.3	45.5	38.9	34.4	35.7	31.6	29.9
BISULFITE SULFUR, G/L	17.5	23.9	27.9	32.3	38.6	48.9	49.6	55.8	59.6
SULFATE SULFUR, G/L	56.3	54.1	54.0	53.2	53.5	54.5	53.8	53.9	56.0
PH	6.55	6.39	6.26	6.15	6.19	5.94	5.85	5.86	5.70
SPECIFIC GRAVITY	1.210	1.210	1.220	1.220	1.216	1.220	1.220	1.225	1.230
FORWARD FLOW, GPM	5.8	5.9	5.5	5.5	-	6.0	6.1	5.7	5.7
PERCENT FORWARD FLOW TO G-2	20.	20.	20.	-	20.	20.	20.	20.	20.
RECIRCULATION RATE, GPM									
G-1	26.	26.	26.	0.	29.	29.	29.	29.	[illegible]
G-2	31.	31.	31.	31.	32.	27.	27.	26.	26.
G-3	18.	18.	18.	18.	18.	18.	18.	18.	18.
RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS									
G-1 ELEMENT									
SULFITE SULFUR, G/L	35.3	37.6	32.6	35.1	31.6	25.7	25.5	23.6	22.3
BISULFITE SULFUR, G/L	42.2	43.3	45.2	47.9	51.6	66.5	67.4	70.2	74.2
SULFATE SULFUR, G/L	50.4	52.6	57.3	53.3	56.7	54.5	54.2	54.6	52.9
PH	5.98	5.95	5.90	5.83	5.85	5.65	5.45	5.58	5.50
SPECIFIC GRAVITY	1.200	1.220	1.220	1.220	1.222	1.220	1.229	1.234	1.235
G-2 ELEMENT									
SULFITE SULFUR, G/L	41.4	42.7	46.1	38.8	37.2	28.9	26.9	25.2	22.7
BISULFITE SULFUR, G/L	21.7	24.5	20.2	32.3	35.2	50.5	53.7	58.4	61.6
SULFATE SULFUR, G/L	46.1	48.8	43.8	49.1	48.9	49.2	48.9	48.0	45.2
PH	6.31	6.28	6.15	6.06	6.10	5.82	5.75	5.65	5.59
SPECIFIC GRAVITY	1.190	1.200	1.200	1.190	1.202	1.209	1.209	1.210	1.213
G-3 ELEMENT									
SULFITE SULFUR, G/L	30.7	33.4	32.0	29.7	28.8	22.4	19.5	18.1	18.1
BISULFITE SULFUR, G/L	14.1	16.6	18.5	23.8	25.5	38.4	42.5	45.7	48.6
SULFATE SULFUR, G/L	33.9	36.8	36.8	36.6	37.1	37.8	38.8	36.8	34.0
PH	6.43	6.38	6.32	6.18	6.18	5.85	5.75	5.67	5.60
SPECIFIC GRAVITY	1.140	1.160	1.160	1.150	1.156	1.165	1.165	1.167	1.168
RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS									
G-1 ELEMENT									
SULFITE SULFUR, G/L	33.1	36.5	35.0	33.8	32.0	30.0	24.4	26.0	22.7
BISULFITE SULFUR, G/L	47.0	48.8	50.8	53.2	57.0	68.9	71.4	78.1	76.6
SULFATE SULFUR, G/L	51.4	53.1	53.7	53.8	54.5	51.1	54.7	54.9	53.4
PH	5.83	5.87	5.84	5.80	5.80	5.85	5.58	5.55	5.46
SPECIFIC GRAVITY	1.210	1.220	1.220	1.220	1.221	1.165	1.231	1.233	1.240
G-2 ELEMENT									
SULFITE SULFUR, G/L	40.8	42.0	38.9	38.3	36.7	28.3	26.4	25.2	22.9
BISULFITE SULFUR, G/L	22.8	25.0	29.2	33.1	37.1	51.2	56.6	57.8	61.8
SULFATE SULFUR, G/L	46.7	48.2	49.0	48.6	49.0	49.5	49.8	49.8	49.8
PH	6.28	6.24	6.16	6.08	6.03	5.80	5.74	5.78	5.59
SPECIFIC GRAVITY	1.190	1.200	1.200	1.190	1.202	1.231	1.202	1.204	1.213
G-3 ELEMENT									
SULFITE SULFUR, G/L	31.2	33.4	31.5	29.9	27.7	21.1	19.7	18.3	19.5
BISULFITE SULFUR, G/L	15.1	16.0	19.3	22.7	26.6	40.0	42.5	45.6	49.9
SULFATE SULFUR, G/L	34.9	36.9	34.2	36.2	36.4	38.6	37.7	37.6	36.9
PH	6.41	6.40	6.26	6.15	6.14	5.88	5.75	5.68	5.55
SPECIFIC GRAVITY	1.150	1.160	1.150	1.150	1.160	1.166	1.167	1.166	1.172
PRODUCT LIQUOR FROM SCRUBBER									
SULFITE SULFUR, G/L	29.5	37.2	37.3	34.9	33.4	28.2	25.7	23.0	22.8
BISULFITE SULFUR, G/L	37.2	42.9	44.1	48.1	50.6	64.5	67.1	70.2	72.8
SULFATE SULFUR, G/L	43.5	52.7	52.7	53.0	53.5	54.0	54.7	56.0	55.2
PH	5.95	5.96	5.95	5.85	5.80	5.62	5.63	5.56	5.51
SPECIFIC GRAVITY	1.180	1.210	1.220	1.210	1.220	1.225	1.234	1.234	1.233
PRODUCT WITHDRAWAL, GPM	5.85	5.20	5.16	5.10	6.00	4.92	5.13	5.10	5.16

AMMONIA ABSORPTION PILOT PLANT TEST NO.SST-10 7-21-71

SAMPLE PERIOD	A	B	C	D	E	F	G
GAS TO SCRUBBER							
FLOW RATE, CFM AT 120 F	2600.	2650.	2650.	2650.	2650.	2650.	2650.
TEMPERATURE, F	248.0	253.0	255.0	258.0	260.0	261.0	262.0
DUST, GRAINS/CU.FT.,DRY BASIS	-	-	-	-	-	-	-
SO2, PPM	2640.	2600.	2560.	2800.	2760.	2770.	2760.
EXCESS AIR, PERCENT OXYGEN	5.	4.	4.	4.	4.	4.	4.
GAS FROM SCRUBBER							
G-1 ELEMENT							
SO2, PPM	940.	860.	-	1460.	-	1560.	1840.
G-2 ELEMENT							
SO2, PPM	60.	45.	50.	210.	350.	410.	710.
G-3 ELEMENT							
SO2, PPM	40.	63.	112.	298.	280.	425.	710.
NH3, PPM	42.0000	103.0000	92.0000	21.0000	20.0000	18.0000	17.0000
DUST, GRAINS/CU.FT.	-	-	-	-	0.1407	0.1407	-
TEMPERATURE, F							
WET-BULB	118.	118.	118.	118.	118.	118.	119.
DRY-BULB	119.	118.	118.	118.	118.	118.	120.
PERCENT SO2 REMOVAL	98.48	97.58	95.62	89.36	89.86	84.66	74.28
MAKEUP LIQUOR TO SCRUBBER							
SULFITE SULFUR, G/L	67.7	65.6	62.1	60.5	57.5	54.6	51.7
BISULFITE SULFUR, G/L	14.9	21.0	26.6	31.3	36.7	43.0	48.3
SULFATE SULFUR, G/L	12.8	13.2	14.0	13.5	14.3	14.4	15.0
PH	6.84	6.68	6.59	6.43	6.34	6.25	6.17
SPECIFIC GRAVITY	1.162	-	1.168	1.170	1.172	1.177	1.184
FORWARD FEED, GPM	1.7	1.6	1.5	1.5	1.5	1.4	1.4
PERCENT FORWARD FLOW TO G-3	10.	10.	10.	10.	10.	10.	10.
RECIRCULATION RATE, GPM							
G-1	28.	28.	28.	29.	29.	29.	29.
G-2	25.	25.	25.	25.	25.	25.	25.
G-3	18.	18.	18.	18.	18.	18.	18.
RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS							
G-1 ELEMENT							
SULFITE SULFUR, G/L	35.2	36.3	36.6	33.9	32.7	30.1	29.7
BISULFATE SULFUR, G/L	76.6	77.8	92.0	87.5	94.5	99.0	100.3
SULFATE SULFUR, G/L	23.0	18.1	16.6	16.8	16.2	18.0	17.5
PH	5.72	5.73	5.74	5.65	5.58	5.53	5.50
SPECIFIC GRAVITY	1.203	-	1.200	1.199	1.201	1.212	1.210
G-2 ELEMENT							
SULFITE SULFUR, G/L	39.6	38.8	38.2	35.0	32.1	28.1	25.7
BISULFATE SULFUR, G/L	35.2	35.0	37.7	43.2	51.0	57.4	61.8
SULFATE SULFUR, G/L	14.2	12.5	12.2	12.0	12.0	12.6	12.5
PH	6.20	6.20	6.20	6.04	5.90	5.80	5.70
SPECIFIC GRAVITY	1.148	-	1.144	1.134	1.142	1.153	1.154
G-3 ELEMENT							
SULFITE SULFUR, G/L	18.3	17.9	17.3	17.9	16.0	10.7	10.2
BISULFATE SULFUR, G/L	21.7	19.6	22.9	24.5	28.7	33.3	37.3
SULFATE SULFUR, G/L	12.2	11.3	8.2	7.2	7.7	10.4	8.0
PH	6.18	6.20	6.20	6.12	5.99	5.71	5.65
SPECIFIC GRAVITY	1.092	-	1.082	1.084	1.086	1.089	1.085
RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS							
G-1 ELEMENT							
SULFITE SULFUR, G/L	35.1	35.0	39.2	35.0	32.6	36.6	35.0
BISULFATE SULFUR, G/L	82.1	82.0	85.0	89.3	97.9	96.3	99.3
SULFATE SULFUR, G/L	22.0	18.5	13.3	16.5	16.7	17.4	17.5
PH	5.69	5.70	5.70	5.65	5.60	5.50	5.50
SPECIFIC GRAVITY	1.200	-	1.200	1.204	1.206	1.218	1.212
G-2 ELEMENT							
SULFITE SULFUR, G/L	38.4	38.2	37.4	34.7	31.7	27.5	25.1
BISULFATE SULFUR, G/L	37.3	36.6	39.5	44.7	51.5	59.5	63.9
SULFATE SULFUR, G/L	14.6	12.5	12.0	11.9	12.0	13.0	12.3
PH	6.18	6.19	6.13	6.00	5.90	5.84	5.70
SPECIFIC GRAVITY	1.145	-	1.140	1.140	1.148	1.155	1.156
G-3 ELEMENT							
SULFITE SULFUR, G/L	19.8	19.4	20.0	13.2	15.4	12.7	8.7
BISULFATE SULFUR, G/L	23.8	20.2	21.3	25.5	30.7	35.6	38.7
SULFATE SULFUR, G/L	12.9	10.3	8.3	12.0	7.9	8.2	9.7
PH	6.16	6.22	6.22	5.96	5.95	5.74	5.55
SPECIFIC GRAVITY	1.100	-	1.085	1.082	1.100	1.090	1.091
PRODUCT LIQUOR FROM SCRUBBER							
SULFITE SULFUR, G/L	36.7	37.5	36.5	36.4	32.0	30.8	29.5
BISULFITE SULFUR, G/L	77.2	77.9	79.8	86.1	91.9	97.5	100.0
SULFATE SULFUR, G/L	20.0	16.6	16.5	14.9	16.4	17.9	17.8
PH	5.74	5.75	5.73	5.70	5.62	5.60	5.52
SPECIFIC GRAVITY	1.201	-	1.200	1.201	1.201	1.208	1.214
PRODUCT BLEEDOFF, GPM	1.77	1.93	1.52	1.52	1.70	1.27	1.86

AMMONIA ABSORPTION PILOT PLANT TEST NO.SST11R 8-23-71

SAMPLE PERIOD	A	B	C	D	E
GAS TO SCRUBBER					
FLOW RATE, CFM AT 120 F	2700.	2700.	2700.	2700.	2700.
TEMPERATURE, F	278.0	288.0	288.0	287.0	287.0
DUST, GRAINS/CU.FT.,DRY BASIS	-	-	-	-	-
SO2, PPM	1900.	1920.	2000.	2020.	2055.
EXCESS AIR, PERCENT OXYGEN	-	-	-	-	-
GAS FROM SCRUBBER					
G-1 ELEMENT					
SO2, PPM	-	-	-	-	-
G-2 ELEMENT					
SO2, PPM	17.	130.	320.	660.	890.
G-3 ELEMENT					
SO2, PPM	16.	30.	190.	516.	812.
NH3, PPM	-	32.0000	5.0000	12.0000	13.0000
DUST, GRAINS/CU.FT.	-	-	-	-	-
TEMPERATURE, F					
WET-BULB	121.	127.	124.	125.	123.
DRY-BULB	122.	128.	125.	126.	124.
PERCENT SO2 REMOVAL	99.16	98.44	90.50	74.46	60.49
MAKEUP LIQUOR TO SCRUBBER					
SULFITE SULFUR, G/L	28.7	24.7	21.2	17.5	15.9
BISULFITE SULFUR, G/L	1.6	11.6	16.4	19.9	25.9
SULFATE SULFUR, G/L	107.8	107.9	109.8	103.3	110.6
PH	7.03	6.20	6.10	5.88	5.90
SPECIFIC GRAVITY	1.250	1.257	1.251	1.240	1.292
FORWARD FEED, GPM	5.6	5.4	5.7	540.0	5.3
PERCENT FORWARD FLOW TO G-3	20.	20.	20.	20.	20.
RECIRCULATION RATE, GPM					
G-1	30.	22.	20.	20.	20.
G-2	24.	26.	28.	29.	29.
G-3	19.	19.	19.	19.	19.
RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	14.1	13.2	11.1	9.1	9.5
BISULFATE SULFUR, G/L	28.6	34.1	38.6	41.3	42.8
SULFATE SULFUR, G/L	105.9	112.0	115.1	113.8	116.5
PH	5.62	5.33	5.50	5.45	5.38
SPECIFIC GRAVITY	1.258	1.298	1.307	1.304	1.310
G-2 ELEMENT					
SULFITE SULFUR, G/L	19.4	0.0	12.3	10.2	2.4
BISULFATE SULFUR, G/L	12.2	0.0	28.9	30.3	27.7
SULFATE SULFUR, G/L	94.3	0.0	97.9	94.3	90.5
PH	6.14	0.00	5.63	5.56	5.15
SPECIFIC GRAVITY	1.228	0.000	1.239	1.250	1.216
G-3 ELEMENT					
SULFITE SULFUR, G/L	15.3	11.4	7.2	6.9	6.1
BISULFATE SULFUR, G/L	8.1	12.4	23.3	24.9	28.0
SULFATE SULFUR, G/L	73.2	72.1	71.9	74.2	73.1
PH	6.37	5.94	5.55	5.45	5.39
SPECIFIC GRAVITY	1.181	1.182	1.184	1.184	1.189
RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	12.5	11.2	10.6	9.2	7.8
BISULFATE SULFUR, G/L	33.0	37.7	39.9	43.9	46.0
SULFATE SULFUR, G/L	110.6	114.5	113.2	115.5	118.5
PH	5.51	5.45	5.50	5.45	5.38
SPECIFIC GRAVITY	1.292	1.300	1.303	1.315	1.314
G-2 ELEMENT					
SULFITE SULFUR, G/L	16.8	13.8	10.7	8.9	8.4
BISULFATE SULFUR, G/L	16.0	23.0	20.7	32.6	34.9
SULFATE SULFUR, G/L	92.0	93.1	76.2	93.8	94.9
PH	5.99	5.72	5.70	5.40	5.38
SPECIFIC GRAVITY	1.225	1.299	1.192	1.230	1.243
G-3 ELEMENT					
SULFITE SULFUR, G/L	14.5	10.1	11.9	6.5	5.5
BISULFATE SULFUR, G/L	9.9	15.9	28.4	27.0	29.3
SULFATE SULFUR, G/L	73.0	70.6	95.8	74.1	74.9
PH	6.13	5.82	5.60	5.40	5.35
SPECIFIC GRAVITY	1.185	1.180	1.235	1.188	1.196
PRODUCT LIQUOR FROM SCRUBBER					
SULFITE SULFUR, G/L	14.1	13.6	10.9	10.2	8.2
BISULFITE SULFUR, G/L	29.0	34.5	37.9	41.7	41.8
SULFATE SULFUR, G/L	106.6	110.3	113.9	114.9	113.7
PH	5.62	5.50	5.50	5.48	5.40
SPECIFIC GRAVITY	1.263	1.292	1.300	1.306	1.303
PRODUCT BLEEDOFF, GPM	5.38	5.62	5.70	5.54	5.79

AMMONIA ABSORPTION PILOT PLANT TEST NO.SST-12 7-29-71

SAMPLE PERIOD	A	B	C	D	E	F	G	H	I
GAS TO SCRUBBER									
FLOW RATE, CFM AT 120 F	3000.	3000.	3000.	-	3000.	3000.	3000.	3000.	3000.
TEMPERATURE, F	224.0	219.0	221.0	-	221.0	227.0	227.0	224.0	223.0
DUST, GRAINS/CU.FT.,DRY BASIS	0.4987	-	-	-	-	-	-	-	-
SO2, PPM	2940.	2880.	2880.	2880.	840.	2640.	2600.	2880.	2760.
EXCESS AIR, PERCENT OXYGEN	2.	2.	3.	2.	2.	2.	3.	3.	3.
GAS FROM SCRUBBER									
G-1 ELEMENT									
SO2, PPM	987.	610.	730.	-	1120.	-	1220.	1507.	-
G-2 ELEMENT									
SO2, PPM	65.	72.	20.	-	-	230.	250.	-	-
G-3 ELEMENT									
SO2, PPM	54.	78.	18.	-	130.	-	320.	534.	770.
NH3, PPM	1.0000	3.0000	5.0000	-	7.0000	4.0000	6.0000	4.0000	4.0000
DUST, GRAINS/CU.FT.	0.1942	-	-	-	-	-	-	-	-
TEMPERATURE, F									
WET-BULB	118.	119.	119.	-	117.	117.	117.	116.	117.
DRY-BULB	118.	120.	119.	-	118.	119.	118.	117.	118.
PERCENT SO2 REMOVAL	98.10	97.29	99.30	-	95.72	-	87.40	88.08	72.10
MAKEUP LIQUOR TO SCRUBBER									
SULFITE SULFUR, G/L	32.7	30.5	26.3	25.5	21.7	20.2	17.5	16.1	14.0
BISULFITE SULFUR, G/L	7.5	11.0	16.6	20.5	26.6	29.9	33.4	36.4	39.1
SULFATE SULFUR, G/L	10.6	8.0	7.8	9.1	9.9	9.7	11.1	10.5	10.9
PH	6.90	6.70	6.51	6.35	6.15	6.05	5.95	5.80	5.60
SPECIFIC GRAVITY	1.090	1.072	1.072	1.080	1.087	1.089	1.095	1.090	1.095
FORWARD FEED, GPM	5.4	5.4	5.0	-	-	5.8	5.0	4.0	4.0
PERCENT FORWARD FLOW TO G-2	20.	20.	20.	-	-	20.	20.	20.	20.
RECIRCULATION RATE, GPM									
G-1	29.	29.	29.	-	20.	28.	28.	29.	29.
G-2	28.	28.	28.	-	22.	23.	23.	23.	23.
G-3	18.	18.	18.	-	18.	18.	18.	18.	18.
RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS									
G-1 ELEMENT									
SULFITE SULFUR, G/L	12.0	11.7	9.9	6.1	8.0	5.8	6.6	6.0	3.6
BISULFATE SULFUR, G/L	38.2	49.4	49.7	47.9	50.8	51.9	53.8	55.3	37.0
SULFATE SULFUR, G/L	11.6	8.1	10.3	13.8	10.5	13.7	11.4	10.7	8.6
PH	5.70	5.67	5.60	5.37	5.50	5.27	5.35	5.20	5.50
SPECIFIC GRAVITY	1.097	1.080	1.088	1.101	1.100	1.112	1.100	1.115	1.067
G-2 ELEMENT									
SULFITE SULFUR, G/L	22.5	21.3	20.1	20.0	14.0	12.2	7.0	11.6	5.9
BISULFATE SULFUR, G/L	14.6	19.4	22.3	21.5	31.9	36.4	39.7	42.4	46.7
SULFATE SULFUR, G/L	10.1	8.3	8.9	9.6	10.1	9.6	13.5	7.4	12.7
PH	6.40	6.35	6.27	6.28	5.30	5.75	5.51	5.50	5.40
SPECIFIC GRAVITY	1.083	1.075	1.063	1.080	1.090	1.090	1.086	1.102	1.090
G-3 ELEMENT									
SULFITE SULFUR, G/L	19.0	16.6	14.7	14.5	11.0	9.0	6.2	7.6	6.4
BISULFATE SULFUR, G/L	6.4	13.0	18.7	23.7	26.1	29.3	32.9	32.9	55.6
SULFATE SULFUR, G/L	8.5	5.5	7.5	8.4	8.7	8.5	9.0	9.6	12.0
PH	6.50	6.48	6.28	6.05	5.95	5.70	5.65	5.65	5.15
SPECIFIC GRAVITY	1.061	1.050	1.062	1.076	1.076	1.076	1.077	1.080	1.104
RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS									
G-1 ELEMENT									
SULFITE SULFUR, G/L	11.2	12.8	10.4	10.2	8.1	6.7	5.8	6.9	2.1
BISULFATE SULFUR, G/L	40.6	42.5	48.0	47.2	52.6	54.0	56.6	57.7	58.6
SULFATE SULFUR, G/L	10.7	8.3	10.6	10.4	10.6	11.6	11.3	9.7	14.3
PH	5.60	5.75	5.40	5.55	5.48	5.33	5.25	5.00	5.10
SPECIFIC GRAVITY	1.090	1.085	1.090	1.089	1.100	1.102	1.102	1.115	1.104
G-2 ELEMENT									
SULFITE SULFUR, G/L	21.0	19.4	19.2	0.0	11.7	11.5	7.0	6.5	5.2
BISULFATE SULFUR, G/L	15.3	18.5	24.1	0.0	34.3	37.6	41.8	43.9	46.2
SULFATE SULFUR, G/L	10.0	9.9	9.5	0.0	12.4	10.0	11.9	10.6	13.5
PH	6.40	6.35	6.20	0.00	5.75	5.70	5.90	5.45	5.30
SPECIFIC GRAVITY	1.080	1.061	1.081	0.000	1.094	1.089	1.095	1.101	1.056
G-3 ELEMENT									
SULFITE SULFUR, G/L	16.4	16.5	14.0	14.6	11.6	8.7	6.5	4.7	4.9
BISULFATE SULFUR, G/L	9.6	12.6	17.2	24.1	27.0	29.6	33.3	35.5	37.0
SULFATE SULFUR, G/L	7.8	4.3	8.3	6.7	8.9	8.8	8.8	6.4	1.6
PH	6.90	6.49	6.30	6.04	5.90	5.77	5.63	5.40	5.10
SPECIFIC GRAVITY	1.041	1.057	1.062	1.070	1.060	1.071	1.071	1.070	1.066
PRODUCT LIQUOR FROM SCRUBBER									
SULFITE SULFUR, G/L	12.5	14.5	12.6	9.5	9.1	7.8	6.7	5.8	5.6
BISULFITE SULFUR, G/L	35.7	39.2	44.3	47.1	49.5	51.4	53.8	55.3	56.4
SULFATE SULFUR, G/L	16.7	7.5	8.4	10.8	10.5	11.0	10.9	10.7	8.9
PH	5.70	5.80	5.70	5.55	5.54	5.49	5.35	5.22	5.15
SPECIFIC GRAVITY	1.091	1.092	1.099	1.100	1.115	1.103	1.104	1.108	1.089
PRODUCT BLOWDOWN, GPM	4.85	4.77	4.51	0.00	0.00	4.83	4.03	4.83	4.83

AMMONIA ABSORPTION PILOT PLANT TEST NO.SST-13   7-30-71

SAMPLE PERIOD	A	B	C	D	E	F
GAS TO SCRUBBER						
FLOW RATE, CFM AT 120 F	2700.	2650.	2650.	2650.	2650.	2650.
TEMPERATURE, F	255.0	258.0	260.0	260.0	260.0	260.0
DUST, GRAINS/CU.FT.,DRY BASIS	0.5079	-	-	-	-	-
SO2, PPM	2680.	2680.	2800.	2800.	2800.	2800.
EXCESS AIR, PERCENT OXYGEN	3.	3.	3.	3.	3.	3.
GAS FROM SCRUBBER						
G-1 ELEMENT						
SO2, PPM	1800.	-	2020.	2160.	2240.	-
G-2 ELEMENT						
SO2, PPM	490.	-	-	-	-	-
G-3 ELEMENT						
SO2, PPM	435.	490.	740.	885.	1080.	1173.
NH3, PPM	6.0000	8.0000	8.0000	7.0000	8.0000	8.0000
DUST, GRAINS/CU.FT.	0.1416	0.0448	-	-	-	-
TEMPERATURE, F						
WET-BULB	121.	120.	120.	119.	119.	119.
DRY-BULB	122.	121.	121.	120.	120.	120.
PERCENT SO2 REMOVAL	83.77	81.72	73.57	68.39	61.43	58.11
MAKEUP LIQUOR TO SCRUBBER						
SULFITE SULFUR, G/L	32.3	30.9	29.2	27.4	27.3	23.9
BISULFITE SULFUR, G/L	5.8	9.8	12.3	16.1	18.5	20.9
SULFATE SULFUR, G/L	10.3	9.6	10.5	10.5	13.2	14.3
PH	7.03	6.77	6.65	6.48	6.40	6.35
SPECIFIC GRAVITY	1.091	1.089	1.088	1.096	1.093	1.093
FORWARD FEED, GPM	2.0	1.9	1.9	1.9	1.8	1.7
PERCENT FORWARD FLOW TO G-3	20.	20.	20.	20.	20.	20.
RECIRCULATION RATE, GPM						
G-1	28.	28.	28.	28.	28.	28.
G-2	27.	27.	27.	28.	28.	28.
G-3	18.	18.	18.	18.	18.	18.
RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS						
G-1 ELEMENT						
SULFITE SULFUR, G/L	3.2	4.1	4.3	4.1	3.8	3.9
BISULFATE SULFUR, G/L	54.3	57.9	39.1	41.3	60.1	61.7
SULFATE SULFUR, G/L	12.7	12.8	10.8	10.3	13.1	13.7
PH	5.17	5.20	5.40	5.40	5.15	5.15
SPECIFIC GRAVITY	1.104	1.106	1.077	1.087	1.111	1.117
G-2 ELEMENT						
SULFITE SULFUR, G/L	6.4	6.6	1.5	3.9	3.4	0.0
BISULFATE SULFUR, G/L	32.8	36.5	59.6	61.3	46.7	0.0
SULFATE SULFUR, G/L	9.4	8.9	15.4	12.9	12.0	0.0
PH	5.65	5.55	4.94	5.13	5.32	0.00
SPECIFIC GRAVITY	1.076	1.078	1.110	1.117	1.086	0 000
G-3 ELEMENT						
SULFITE SULFUR, G/L	2.5	3.3	2.5	1.5	2.6	0.0
BISULFATE SULFUR, G/L	23.6	25.3	27.4	28.9	29.5	0.0
SULFATE SULFUR, G/L	8.3	7.4	6.1	8.6	7.3	0.0
PH	5.55	5.55	5.45	5.35	5.30	0.00
SPECIFIC GRAVITY	1.053	1.056	1.058	1.056	1.056	0.000
RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS						
G-1 ELEMENT						
SULFITE SULFUR, G/L	1.9	2.2	4.0	1.8	3.2	3.5
BISULFATE SULFUR, G/L	50.9	59.0	61.9	62.8	63.0	63.9
SULFATE SULFUR, G/L	11.0	14.0	13.0	15.2	16.2	15.6
PH	5.06	4.99	5.15	4.88	5.02	5.12
SPECIFIC GRAVITY	1.100	1.110	1.108	1.123	1.121	1.120
G-2 ELEMENT						
SULFITE SULFUR, G/L	4.6	4.6	-0.5	1.2	3.6	2.3
BISULFATE SULFUR, G/L	34.8	38.5	40.7	45.9	44.0	45.1
SULFATE SULFUR, G/L	10.7	10.4	15.3	10.2	25.8	11.2
PH	5.50	5.42	4.70	5.33	5.34	5.24
SPECIFIC GRAVITY	1.078	1.081	1.082	1.087	1.083	1.090
G-3 ELEMENT						
SULFITE SULFUR, G/L	0.8	-1.5	2.2	0.5	2.8	-1.3
BISULFATE SULFUR, G/L	23.7	26.1	28.4	30.0	30.5	31.4
SULFATE SULFUR, G/L	9.4	11.7	7.8	8.5	10.7	11.2
PH	5.54	4.60	5.39	5.20	5.26	5.01
SPECIFIC GRAVITY	1.054	1.051	1.054	1.059	1.057	1.070
PRODUCT LIQUOR FROM SCRUBBER						
SULFITE SULFUR, G/L	[illegible]	4.3	4.5	3.4	3.0	1.9
BISULFITE SULFUR, G/L	41.9	55.7	59.3	61.3	60.6	62.7
SULFATE SULFUR, G/L	10.4	12.1	12.2	12.8	14.3	17.0
PH	5.22	5.25	5.25	5.10	5.15	5.16
SPECIFIC GRAVITY	1.084	1.103	1.109	1.119	1.112	1.118
PRODUCT BLEEDOFF, GPM	1.81	[illegible]	1.76	1.83	1.74	2.21

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        AMMONIA ABSORPTION PILOT PLANT TEST NO.SST-14   8-2-71


                                                       A          B          C
SAMPLE PERIOD
GAS TO SCRUBBER
  FLOW RATE, CFM AT 120 F                          2600.      2600.      2600.
  TEMPERATURE, F                                   260.0      265.0      265.0
  DUST, GRAINS/CU.FT.,DRY BASIS                   0.5453         -          -
  SO2, PPM                                         3020.      2920.      2840.
  EXCESS AIR, PERCENT OXYGEN                          3.         3.         2.

GAS FROM SCRUBBER
  G-1 ELEMENT
    SO2, PPM                                        640.      1520.      1720.

  G-2 ELEMENT
    SO2, PPM                                        120.       280.       600.

  G-3 ELEMENT
    SO2, PPM                                         94.       180.       657.
    NH3, PPM                                     47.0000    12.0000     7.0000
    DUST, GRAINS/CU.FT.                           0.0719         -      0.0709
    TEMPERATURE, F
      WET-BULB                                      120.       121.       121.
      DRY-BULB                                      121.       121.       122.

PERCENT SO2 REMOVAL                                96.89      93.84      76.87

MAKEUP LIQUOR TO SCRUBBER
  SULFITE SULFUR, G/L                               27.0       20.3       15.6
  BISULFITE SULFUR, G/L                             12.4       24.1       32.6
  SULFATE SULFUR, G/L                                6.7        7.9       10.8
  PH                                                6.53       6.21       5.95
  SPECIFIC GRAVITY                                 1.084      1.089      1.088
  FORWARD FEED, GPM                                  5.0        5.2        5.7
  PERCENT FORWARD FLOW TO G-3                        10.        10.        10.

RECIRCULATION RATE, GPM
  G-1                                                28.        28.        28.
  G-2                                                25.        27.        28.
  G-3                                                23.        23.        22.

RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS
  G-1 ELEMENT
    SULFITE SULFUR, G/L                             12.7        7.6        5.5
    BISULFATE SULFUR, G/L                           38.2       47.6       51.6
    SULFATE SULFUR, G/L                              9.1        9.9       12.1
    PH                                              5.77       5.48       5.28
    SPECIFIC GRAVITY                               1.094      1.099      1.096

  G-2 ELEMENT
    SULFITE SULFUR, G/L                             19.6       12.1        7.7
    BISULFATE SULFUR, G/L                           16.8       31.0       38.2
    SULFATE SULFUR, G/L                              6.5        7.1       11.5
    PH                                              6.37       5.89       5.49
    SPECIFIC GRAVITY                               1.077      1.082      1.082

  G-3 ELEMENT
    SULFITE SULFUR, G/L                             11.6        5.6       -4.0
    BISULFATE SULFUR, G/L                           10.4       22.0       29.3
    SULFATE SULFUR, G/L                              3.0        6.7       14.0
    PH                                              6.45       5.81       3.40
    SPECIFIC GRAVITY                               1.049      1.056      1.079

RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS
  G-1 ELEMENT
    SULFITE SULFUR, G/L                             10.3        5.9        4.1
    BISULFATE SULFUR, G/L                           43.2       51.5       53.9
    SULFATE SULFUR, G/L                             12.1       11.4       14.4
    PH                                              5.63       5.35       5.20
    SPECIFIC GRAVITY                               1.098      1.103      1.101

  G-2 ELEMENT
    SULFITE SULFUR, G/L                             16.2       11.4        7.0
    BISULFATE SULFUR, G/L                           17.9       32.6       39.9
    SULFATE SULFUR, G/L                              9.5        6.3        8.6
    PH                                              6.27       5.83       5.51
    SPECIFIC GRAVITY                               1.077      1.082      1.090

  G-3 ELEMENT
    SULFITE SULFUR, G/L                             11.5        6.1        1.6
    BISULFATE SULFUR, G/L                           10.7       22.9       28.7
    SULFATE SULFUR, G/L                              6.0        6.4       10.9
    PH                                              6.42       5.80       5.42
    SPECIFIC GRAVITY                               1.050      1.056      1.070


PRODUCT LIQUOR FROM SCRUBBER
  SULFITE SULFUR, G/L                               12.3        4.3        4.8
  BISULFITE SULFUR, G/L                             37.7       46.8       51.5
  SULFATE SULFUR, G/L                                9.9       14.1       12.5
  PH                                                5.77       5.27       5.30
  SPECIFIC GRAVITY                                 1.094      1.099      1.097
  PRODUCT BLEED-OFF, GPM                            5.13       5.10       6.15
```

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      AMMONIA ABSORPTION PILOT PLANT TEST NO.SST-19   8-4-71


SAMPLE PERIOD                                          A          B          C          D
GAS TO SCRUBBER
  FLOW RATE, CFM AT 120 F                          2700.      2700.      2700.      2700.
  TEMPERATURE, F                                   222.0      224.0      227.5      226.5
  DUST, GRAINS/CU.FT.,DRY BASIS                   0.4966          -          -          -
  SO2, PPM                                         2680.      2720.      2880.      2820.
  EXCESS AIR, PERCENT OXYGEN                          3.         3.         4.         3.

GAS FROM SCRUBBER
  G-1 ELEMENT
    SO2, PPM                                           -       300.       735.       880.

  G-2 ELEMENT
    SO2, PPM                                           -       300.          -          -

  G-3 ELEMENT
    SO2, PPM                                           -          -       135.       310.
    NH3, PPM                                    380.0000   224.0000    40.0000     8.0000
    DUST, GRAINS/CU.FT.                           0.0559     0.1131     0.0000     0.0000
    TEMPERATURE, F
      WET-BULB                                      119.       120.       118.       119.
      DRY-BULB                                      119.       120.       120.       121.

PERCENT SO2 REMOVAL                                    -          -      95.31      69.01

MAKEUP LIQUOR TO SCRUBBER
  SULFITE SULFUR, G/L                               51.4       42.3       37.0       31.3
  BISULFITE SULFUR, G/L                             22.3       35.0       46.1       55.1
  SULFATE SULFUR, G/L                                9.8       10.9       10.0        9.9
  PH                                                6.60       6.29       6.05       5.93
  SPECIFIC GRAVITY                                 1.139      1.144      1.145      1.140
  FORWARD FEED, GPM                                  4.6        5.5        5.4        5.6
  PERCENT FORWARD FLOW TO G-3                         10.        10.        10.         0.

RECIRCULATION RATE, GPM
  G-1                                                27.        27.        27.        27.
  G-2                                                24.        26.        27.        27.
  G-3                                                16.        17.        18.        18.

RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS
  G-1 ELEMENT
    SULFITE SULFUR, G/L                             36.8       30.4       25.8       19.8
    BISULFATE SULFUR, G/L                           44.0       56.6       65.0       71.9
    SULFATE SULFUR, G/L                             10.1       10.7       10.7       10.8
    PH                                              6.08       5.85       5.72       5.55
    SPECIFIC GRAVITY                               1.139      1.151      1.152      1.153

  G-2 ELEMENT
    SULFITE SULFUR, G/L                             44.2       36.3       33.6       22.0
    BISULFATE SULFUR, G/L                           23.1       33.6       41.7       52.8
    SULFATE SULFUR, G/L                             10.4        8.9        9.6       14.0
    PH                                              6.45       6.21       6.05       5.74
    SPECIFIC GRAVITY                               1.123      1.133      1.133      1.137

  G-3 ELEMENT
    SULFITE SULFUR, G/L                             42.9       37.9       31.1       22.1
    BISULFATE SULFUR, G/L                           22.7       32.4       42.3       50.9
    SULFATE SULFUR, G/L                              8.6        8.7        9.4       11.5
    PH                                              6.45       6.25       6.04       5.77
    SPECIFIC GRAVITY                               1.121      1.128      1.132      1.131


RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS
  G-1 ELEMENT
    SULFITE SULFUR, G/L                             37.0       31.2       19.8       22.0
    BISULFATE SULFUR, G/L                           42.5       54.8       64.3       69.5
    SULFATE SULFUR, G/L                             10.1       10.3       16.0       10.1
    PH                                              6.11       5.90       5.65       5.58
    SPECIFIC GRAVITY                               1.140      1.147      1.157      1.149

  G-2 ELEMENT
    SULFITE SULFUR, G/L                             43.2       38.5       33.8       25.7
    BISULFATE SULFUR, G/L                           23.9       33.0       41.5       54.5
    SULFATE SULFUR, G/L                              9.7        8.7        9.5        9.3
    PH                                              6.42       6.20       6.05       5.78
    SPECIFIC GRAVITY                               1.127      1.131      1.134      1.138

  G-3 ELEMENT
    SULFITE SULFUR, G/L                             42.3       38.2       31.2       25.6
    BISULFATE SULFUR, G/L                           23.4       33.1       43.5       51.9
    SULFATE SULFUR, G/L                              9.2        8.5        9.4        9.1
    PH                                              6.46       6.25       6.00       5.84
    SPECIFIC GRAVITY                               1.124      1.128      1.127      1.130


PRODUCT LIQUOR FROM SCRUBBER
  SULFITE SULFUR, G/L                               36.5       26.9       26.5       20.8
  BISULFITE SULFUR, G/L                             43.6       53.7       63.5       72.5
  SULFATE SULFUR, G/L                               11.7       15.2       10.5        9.9
  PH                                                6.10       5.85       5.75       5.58
  SPECIFIC GRAVITY                                 1.140      1.148      1.154      1.153
  PRODUCT BLEEDOFF, GPM                             5.82       5.48       5.52       5.91
```

AMMONIA ABSORPTION PILOT PLANT TEST NO.SST-16R 8-24-71

SAMPLE PERIOD	A	B	C	D	E
GAS TO SCRUBBER					
FLOW RATE, CFM AT 120 F	2700.	2700.	2700.	2700.	2700.
TEMPERATURE, F	221.0	225.0	230.0	232.0	226.0
DUST, GRAINS/CU.FT.,DRY BASIS	-	-	-	-	-
SO2, PPM	2560.	2610.	2710.	2700.	2820.
EXCESS AIR, PERCENT OXYGEN	3.	3.	3.	3.	3.
GAS FROM SCRUBBER					
G-1 ELEMENT					
SO2, PPM	2280.	2360.	2500.	2520.	2600.
G-2 ELEMENT					
SO2, PPM	1600.	1500.	1870.	2020.	2210.
G-3 ELEMENT					
SO2, PPM	-	1200.	1490.	1640.	1820.
NH3, PPM	-	7.0000	6.0000	6.0000	6.0000
DUST, GRAINS/CU.FT.	-	-	-	-	-
TEMPERATURE, F					
WET-BULB	121.	121.	121.	121.	121.
DRY-BULB	122.	122.	122.	122.	122.
PERCENT SO2 REMOVAL	-	54.02	45.02	39.26	35.46
MAKEUP LIQUOR TO SCRUBBER					
SULFITE SULFUR, G/L	21.6	27.7	24.0	22.6	20.8
BISULFITE SULFUR, G/L	3.1	2.6	6.8	9.1	12.8
SULFATE SULFUR, G/L	93.9	108.3	104.4	107.5	104.8
PH	6.75	6.90	6.50	6.35	6.20
SPECIFIC GRAVITY	1.220	1.250	1.238	1.243	1.241
FORWARD FEED, GPM	1.6	1.5	1.5	1.5	1.4
PERCENT FORWARD FLOW TO G-3	20.	20.	20.	20.	20.
RECIRCULATION RATE, GPM					
G-1	24.	24.	23.	23.	23.
G-2	28.	28.	28.	28.	28.
G-3	17.	17.	17.	17.	17.
RECIRCULATING LIQUOR TO SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	3.0	5.1	5.2	3.1	4.9
BISULFATE SULFUR, G/L	35.2	36.9	38.0	38.3	39.3
SULFATE SULFUR, G/L	83.5	91.3	94.6	99.1	96.4
PH	5.05	5.15	5.15	5.00	5.09
SPECIFIC GRAVITY	1.209	1.232	1.232	1.245	1.240
G-2 ELEMENT					
SULFITE SULFUR, G/L	3.9	4.1	6.2	1.8	4.6
BISULFATE SULFUR, G/L	30.2	30.6	31.7	31.5	32.9
SULFATE SULFUR, G/L	76.9	80.6	82.7	88.4	83.0
PH	5.40	5.16	5.27	4.91	5.10
SPECIFIC GRAVITY	1.190	1.205	1.208	1.211	1.208
G-3 ELEMENT					
SULFITE SULFUR, G/L	1.6	3.1	3.0	1.7	2.8
BISULFATE SULFUR, G/L	23.8	23.4	24.8	25.0	25.5
SULFATE SULFUR, G/L	56.8	58.2	57.2	57.6	57.6
PH	5.05	5.14	5.10	4.99	5.03
SPECIFIC GRAVITY	1.147	1.158	1.156	1.153	1.152
RECIRCULATING LIQUOR FROM SCRUBBER ELEMENTS					
G-1 ELEMENT					
SULFITE SULFUR, G/L	3.0	4.6	4.7	4.8	4.1
BISULFATE SULFUR, G/L	36.2	38.6	38.7	40.0	40.4
SULFATE SULFUR, G/L	86.0	93.3	96.1	99.4	98.6
PH	5.05	5.10	5.10	5.11	5.05
SPECIFIC GRAVITY	1.212	1.233	1.236	1.246	1.243
G-2 ELEMENT					
SULFITE SULFUR, G/L	3.6	5.6	4.4	4.6	4.6
BISULFATE SULFUR, G/L	31.7	31.8	32.9	33.5	34.4
SULFATE SULFUR, G/L	76.7	82.3	83.4	84.4	82.8
PH	5.20	5.25	5.17	5.18	5.15
SPECIFIC GRAVITY	1.194	1.214	1.216	1.214	1.209
G-3 ELEMENT					
SULFITE SULFUR, G/L	2.0	1.4	2.0	1.8	1.4
BISULFATE SULFUR, G/L	24.8	24.2	25.8	25.8	26.5
SULFATE SULFUR, G/L	57.3	79.5	56.8	57.8	58.4
PH	5.10	4.93	5.05	5.09	4.95
SPECIFIC GRAVITY	1.151	1.155	1.154	1.154	1.153
PRODUCT LIQUOR FROM SCRUBBER					
SULFITE SULFUR, G/L	3.7	5.7	5.6	4.7	4.8
BISULFITE SULFUR, G/L	35.9	37.3	37.7	39.2	39.2
SULFATE SULFUR, G/L	84.7	93.4	95.1	99.3	96.4
PH	5.10	5.23	5.25	5.20	5.20
SPECIFIC GRAVITY	1.221	1.239	1.234	1.246	1.241
PRODUCT WITHDRAWAL, GPM	2.09	2.02	1.98	1.95	2.15

APPENDIX D - ANALYTICAL AND GAS SAMPLING PROCEDURES

The wet-chemical analysis procedures, flue gas sampling procedures (particulate, SO_2, and NH_3), and related calculations used in this test work are presented in this appendix.

Iodimetric Method for Analysis of Total Sulfites

Manipulations

Aliquot 25 ml of the scrubber solution into a 1000-ml volumetric flask containing about 300 ml of condensate water. Use caution to see that the discharge end of the pipette is under the water. Dilute to volume. In a 250-ml wide-mouth erlenmeyer flask add 10 ml of 1-10 HCl and 35 ml of 0.1 $\underline{N}$ I_2 (more may be used if necessary). Aliquot 20 ml of the diluted sample under the surface of the iodine. Allow time to react and back titrate the excess I_2 with 0.1 $\underline{N}$ $Na_2S_2O_3$.

Calculations

gm/l total sulfites =

$$\frac{\text{ml } I_2 - (\text{ml } Na_2S_2O_3 \times \underline{N}\ Na_2S_2O_3/\underline{N}\ I_2) \times \underline{N}\ I_2 \times 0.0160324 \times 1000}{\text{ml sample analyzed}} =$$

Alkimetric Method for Analysis of Total Bisulfite Sulfur and Total Sulfur

Manipulations

Aliquot 10 ml of sample to a 250-ml volumetric flask containing about 100 ml of de-ionized water and 10 ml of 30% hydrogen peroxide. Make to volume with de-ionized water and allow to cool and make to volume again, mix thoroughly.

Take a 20-ml aliquot of the diluted sample into a 250-ml, wide-mouth erlenmeyer flask. Add 8 drops of methyl red-methylene blue mixed indicator to the flask. Titrate with approximately 0.2 N NaOH to the first green end point. Record the ml of NaOH used as the titer Ta for calculating the grams per liter of bisulfite sulfur.

Add 10 ml of formaldehyde to the same sample. Add 1 dropper of phenolphtalein-methylene green indicator, continue to titrate with the 0.2 N NaOH through the blue color, through the green color, and to the first dark blue color. Record the ml of NaOH used; this is titer Tb.

Establish a blank on each new bottle of formaldehyde. Add 20 ml of de-ionized water to a 250-ml erlenmeyer flask, add 10 ml of formaldehyde to the flask, add 8 drops of methyl red-methelene blue indicator. Titrate to the green end point with 0.2 N NaOH. The ml of the 0.2 N NaOH used to titrate 10 ml of formaldehyde is the blank.

Calculations

$$\text{gm/l } HSO_3 = \frac{\text{ml NaOH (Ta)} \times \underline{N} \text{ NaOH} \times 0.032064 \times 1000}{\text{ml of sample analyzed}}$$

$$\text{gm/l total sulfur} = \frac{(\text{Ta} + \text{Tb} - \text{blank}) \times \underline{N} \text{ NaOH} \times 0.0160324 \times 1000}{\text{ml of sample analyzed}}$$

Analysis of the Acidulator and Stripper Liquors for Bisulfite, Bisulfate, and Total Sulfur

The total sulfites are determined by the iodimetric method. It is assumed that when the pH of the acidulator is 2.0 or below, that all of the sulfites are in the form of ammonium bisulfite. The acidulator and stripper also contain ammonium bisulfate and ammonium sulfate. The acidulator and stripper are analyzed essentially the same way as the samples from the ammonium scrubber pilot plant, as described above; however, the calculations are somewhat different.

The total sulfites are calculated to ammonium bisulfites. A separate determination is made for the ammonium bisulfate and total sulfur alkimetrically.

Manipulations

Aliquot 10 ml of the sample into a 250-ml volumetric flask containing about 100 ml of de-ionized water and 10 ml of 30% hydrogen peroxide; make to volume with de-ionized water. Take a 20-ml aliquot into a 250-ml erlenmeyer flask. Add to it 10 drops of methyl red-methylene blue mixed indicator. Titrate with 0.2 N NaOH to the green end point, and record ml used as the titer Ta for calculating the ammonium bisulfate. Add 10 ml of formaldehyde to the sample, then 1 dropper of phenolphtalein-methylene green mixed indicator, continue to titrate through the blue color, through the green color, and to a dark blue color. This is the end point for the total sulfur, record mls used as titer Tb.

Establish a blank on each new bottle of formaldehyde. Add 20 ml of de-ionized water to a 250-ml erlenmeyer flask, add 10 ml of formaldehyde to the flask, add 8 drops of methyl red-methylene blue indicator. Titrate to the green end point with 0.2 N NaOH. The ml of 0.2 N NaOH used to titrate 10 ml of formaldehyde is the blank.

Calculations

Ammonium Bisulfate:

$$\text{gm/l}\ \frac{(NH_4HSO_3)(\text{ml sample})}{\underline{N}\ \text{NaOH} \times 99.112} = \text{ml } 0.2\ \underline{N}\ \text{NaOH due to } NH_4HSO_3$$

$$\text{gm/l } NH_4HSO_4 = \frac{(Ta-a) \times \underline{N}\ \text{NaOH} \times 115.112}{\text{ml sample analyzed}}$$

Total Sulfur:

$$\text{gm/l total sulfur} = \frac{(Ta + Tb - \text{blank}) \times \underline{N}\ \text{NaOH} \times 16.0324}{\text{ml sample analyzed}}$$

Ammonia in Exit Flue Gas Sample

(Direct Nesslerization Method)

Method

Nessler reagent and Rochelle salt solution are added to the sample to be tested. The resulting color intensity is determined with a spectrophotometer by taking the light transmittance at 425 millimicrons through a 2.5-cm cell.

The NH_3 concentration in the unknown sample is determined by comparing its color intensity with the color intensities of samples containing known concentration of NH_3. The comparison is made from a graph previously prepared by plotting the light transmitted through the color developed in standard samples against the concentration of ammonia in them.

Manipulations

1. From previous analyses of the same type samples, estimate the concentration of NH_3 in the sample. Then use the tabulation below to determine aliquot to use.

Sample concentration, dilution, and aliquot to use

Approximate concentration, ppm NH_3	Ml of original taken	Volume diluted to, ml	Ml of diluted sample analyzed	Ml original analyzed
0.0 to 1.4	-	-	-	100
1.5 to 2.9	-	-	-	50
3.0 to 7.3	-	-	-	20
7.4 to 14.5	50	500	100	10
14.5 to 29.0	25	500	100	5
29.0 to 58.1	25	500	50	2.5

2. Transfer selected aliquot of filtered samples into separate 100-ml Nessler tubes. If aliquot is less than 100 ml, dilute to 100 ml with ammonia-free distilled water. Always test distilled water for ammonia before using it. If sample is colored or turbid and not water clear, transfer a duplicate aliquot into another Nessler tube. Add 1 ml of Rochelle salt and determine light transmitted through it to make sure it is not darker than reagent blank used to adjust instrument as described below. If its color is darker than reagent blank, adjust instrument with it and determine light transmitted through portion of same sample reacted with Nessler at the new instrument setting.

3. Prepare a reagent blank by adding 100 ml of ammonia-free distilled water to another 100-ml Nessler tube.

4. Add 1 ml of Rochelle salt solution to each sample and reagent blank. Stopper each Nessler tube with clean polyethylene stopper and mix by inverting two or three times. Never use rubber stoppers in this step and step 5 because a color other than ammonia reaction may result.

5. Add 1 ml of Nessler reagent solution to each sample and reagent blank; again, stopper and mix as in step 4. Allow color to develop 30 minutes.

6. Transfer sample containing Rochelle salt and Nessler reagent into spectrophotometer test tube and read percent transmittance.

7. From transmittance reading determine mg NH_4 and/or ppm from a prepared chart.

Calculations

$$\frac{\text{mg } NH_4 \times 1000}{\text{ml of orig. sample used for comparison}} = \text{ppm } NH_4$$

$$\text{ppm } NH_4 \times 0.944 = \text{ppm } NH_3$$

$$\text{ppm } NH_4 \times 0.777 = \text{ppm N}$$

Preparation of Ammonia Reagents

(for Nessler Method)

Nessler Reagent

Dissolve 100 gm mercuric iodide (HgI_2) and 70 gm potassium iodide, (KI) in a small quantity of ammonia-free distilled water and add this mixture slowly, with stirring, to a cool solution of 160 gm NaOH in 500-ml ammonia-free distilled water. Dilute to 1 liter with ammonia-free distilled water.

Stored in Pyrex glassware and out of sunlight, this reagent is stable for periods up to a year under normal laboratory conditions.

The reagent should give the characteristic color with mg/l ammonia nitrogen within 10 minutes after addition but should not produce a precipitate with small amounts of ammonia within 2 hours.

CAUTION: This reagent is very toxic; take care to avoid ingestion.

Rochelle Salt Reagent

Dissolve 500 gm of reagent grade $KNaC_4H_4O_6 \cdot 4H_2O$ in 1 liter of distilled water. Boil off 200 ml or until free from ammonia. Cool and dilute to 1 liter with ammonia-free distilled water.

Preparation of Standard Ammonium Chloride and Ammonium Sulfate Solutions for Calibrating Spectrophotometers

Ammonium Chloride and Ammonium Sulfate Stock Solutions

Dissolve 1.1862 gm anhydrous reagent grade ammonium chloride or 1.4652 gm ammonium sulfate, dried at 100°C, in ammonia-free distilled water and dilute to 2000 ml with NH_3 free distilled water. Mix well.

Standard Solution Containing 0.002 mg NH_4 per ml

Pipet 20 ml of either stock solution and transfer into a 2000 ml volumetric flask. Dilute to 2000 ml with ammonia-free distilled water and mix well. This solution is used for calibrating spectrophotometers.

Procedure for Sampling Inlet or Exit

Flue Gas for Particulate and Sulfur Dioxide

Apparatus (Fig. 44)

A. Environeering Dust Filter

B. Four 600-ml gas scrubber bottles arranged in order listed below. (An additional scrubber bottle of peroxide may be required for inlet determinations.)

  1. Dry trap with short open-end sparger
  2. 6% hydrogen peroxide solution with fritted glass impinger (250 ml)
  3. 6% hydrogen peroxide solution with fritted glass impinger (250 ml)
  4. Dry trap with short open-end sparger

C. Dry test meter

D. Vacuum supply

Procedure

A. Insert Environeering sampling nozzle into gas duct

B. Pull approximately 0.5 cfm sample for about 120 min (increase vacuum to maintain flow)

C. Record pressure and temperature readings at meter

D. Record pressure and temperature readings of duct (wet and dry bulb for exit gas sample)

E. Combine the peroxide bottles and analyze for SO_2

F. Dry the filter paper at 110°F and weigh

Calculations

A. Calculate duct loading of gas (gr/dscf at 70°F) as shown in attached example

B. Calculate SO_2 content in gas (ppm) as shown in attached example

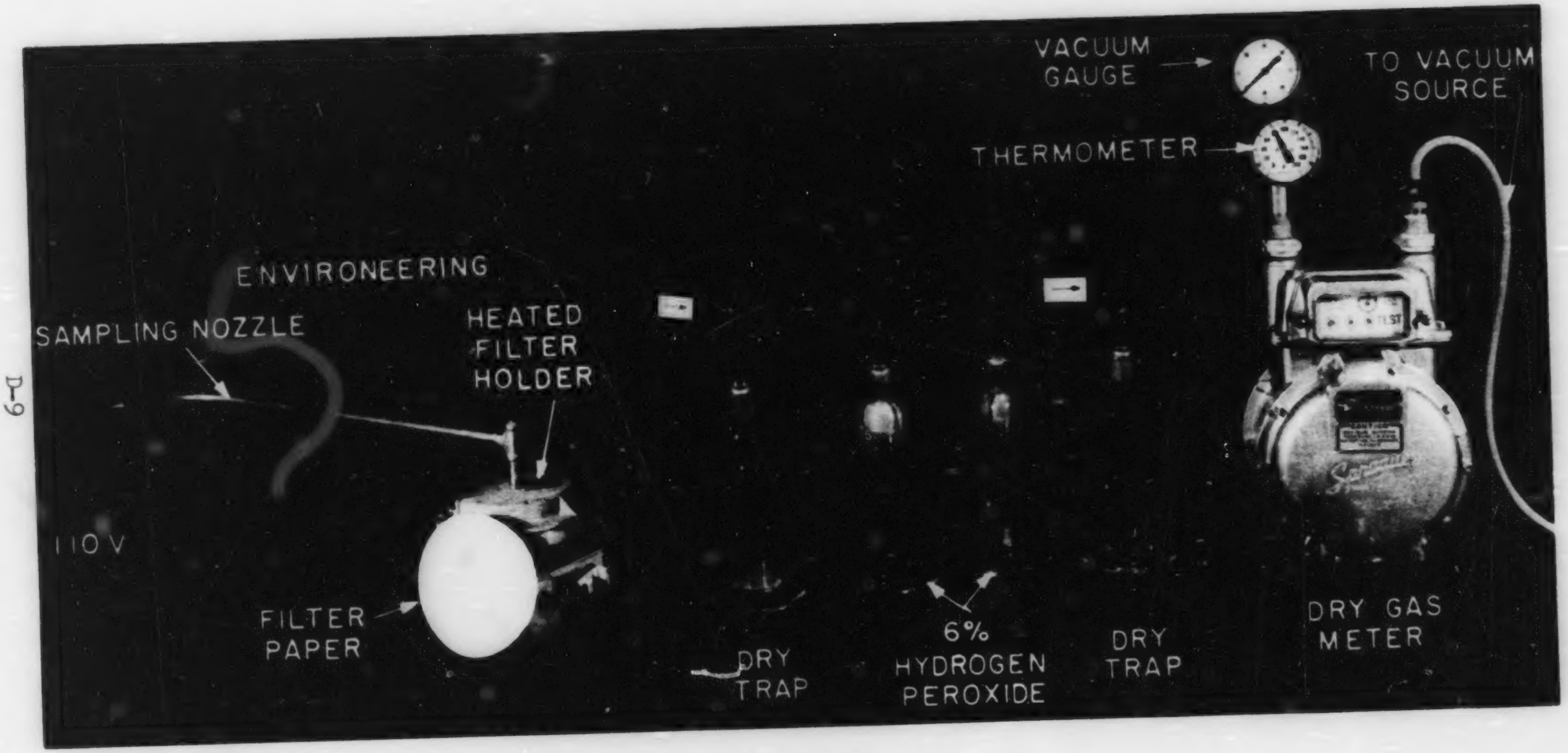

FIGURE 44

Sampling Apparatus for Determining Sulfur Dioxide and Particulate Content of Flue Gas Entering and Leaving the Absorber

Procedure for Sampling Exit Flue Gas for Ammonia

Apparatus (See Fig. 45)

A. Stainless steel sampling nozzle

B. Four 600-ml gas scrubber bottles arranged in order listed below

  1. Dry trap with short open-end sparger
  2. Distilled water with fritted glass impinger (250 ml)
  3. Distilled water with fritted glass impinger (250 ml)
  4. Dry trap with short open-end sparger

C. Dry test meter

D. Vacuum supply

Procedure

A. Insert sampling nozzle into gas duct

B. Pull approximately 0.5 cfm sample for about 30 min (increase vacuum to maintain flow)

C. Record pressure and temperature readings at meter

D. Record pressure and temperature readings of duct (wet and dry bulb)

E. Combine the water bottles and analyze for NH_3 (see analysis procedure)

Calculations

A. Calculate NH_3 content in gas (ppm) as shown in attached sample

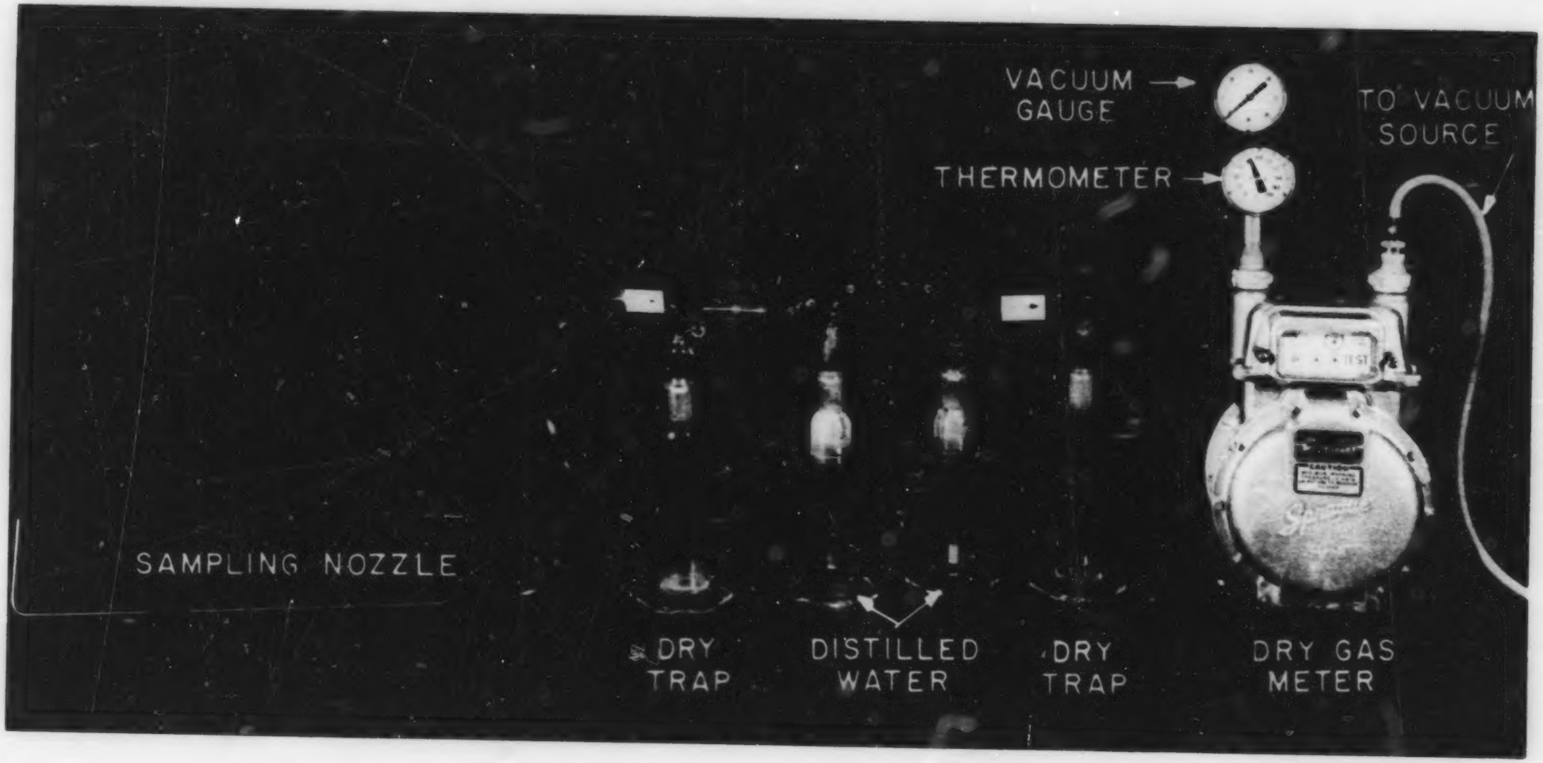

FIGURE 45

Sampling Apparatus for Determining the Ammonia Content of Flue Gas Leaving the Absorber

Sample Calculation Sheet for

Particulate and SO_2 in Inlet Flue Gas

Test Data

Test No....................... RST-15
Date 2/26/71
Sample period .... 10:30 – 11:50 a.m.

Dry test meter readings
    Total volume through meter, ft^3............. 23.2
    Temperature of meter, °F..................... 58
    Vacuum on meter, in Hg 7

Dust collected during sampling period, gm 5.3320
Sulfur caught in peroxide during sampling period, gm 1.89
Average moisture of inlet gas during sampling period, % 7.75

Calculations

1. To convert the volume at meter conditions to the volume at standard conditions, use the pressure–volume–temperature relationship expressed in the ideal gas law.

$$\frac{P_oV_o}{T_o} = \frac{P_1V_1}{T_1}$$

where

P_o = initial pressure, in Hg

V_o = initial volume, ft^3

T_o = initial temperature, °R or (460 + °F)

and P_1, V_1, and T_1 = above values at standard conditions

Transposing,

$$V_1 = \frac{P_oV_oT_1}{T_oP_1}$$

Inserting test data values,

$$V_1 = \frac{(29.92 - 7.0)^{a}(23.2)(460 + 70)}{(460 + 58)(29.92)}$$

---

[a] Vacuum on meter.

$$= \frac{(22.92)(23.2)\ 530}{(518)(29.92)}$$

$$= 18.18\ ft^3$$

Converting from wet volume to dry volume, use the formula

$$V_{dry} = V_{wet}\ \frac{(100 - \text{avg \% moisture by volume})}{100}$$

$$= (18.18)\ \frac{(100 - 7.75)}{100}$$

$$= (18.18)(0.9225)$$

$$= 16.78\ ft^3 \text{ (dry at 29.92 in Hg and 70°F)}$$

2. To convert the weight of dust collected on the filter during the sampling period into dust concentration in gr/dscf$_{70}$, merely convert the weight in gm to gr by multiplying by 15.43 (the number of gr in 1 gm) and divide by the dry volume of gas at standard conditions.

$$\text{Dust loading} = \frac{(5.3320)(15.43)}{16.78}$$

$$= 4.9030\ gr/dscf_{70}$$

3. To convert the weight of sulfur caught in the peroxide bottles into its equivalent volume of SO_2, divide the weight of the sample by the gram molecular weight of sulfur and multiply the quotient by the mol volume (in liters) divided by 28.32 (the number of liters in 1 ft^3).

$$\text{Vol. } SO_2 \text{ sampled} = \frac{\text{Sample weight}}{\text{gm mol wt of S}} \times \frac{22.4}{28.32}$$

$$= \frac{1.89}{32.06} \times 0.791$$

$$= 0.04664$$

To convert the volume of SO_2 sampled to ppm in inlet gas, multiply the volume by 10^6 and divide by the combined volume of SO_2 plus inlet gas.

$$SO_2 \text{ in inlet gas} = \frac{\text{Vol. of } SO_2 \text{ sampled} \times 10^6}{\text{Vol. of } SO_2 \text{ sampled + vol. of gas}}$$

$$= \frac{0.04664 \times 10^6}{0.04664 + 16.78}$$

$$= 2772\ ppm$$

Sample Calculation Sheet for

Particulate and SO_2 in Exit Flue Gas

Test Data

Test No.	RST-15
Date	2/26/71
Sample period	11:00 a.m. – 12:00 noon

Dry test meter readings

Total volume through meter, ft^3	17.8
Temperature of meter, °F	58
Vacuum on meter, in Hg	7

Wet-bulb temp. exit scrubber, °F	105
Dry-bulb temp. exit scrubber, °F	106

Dust collected during sampling, gm	0.005
Sulfur caught in peroxide during sampling, gm	0.33

Calculations

1. To convert the volume of gas from meter conditions to dry standard cubic feet at atmospheric pressure and 70°F, use the formulas below.

$$V_1 = \frac{(29.92 - 7)(17.8)(460 + 70)}{(460 + 58)(29.92)}$$

$$= 13.95$$

$$V_{dry} = V_{wet} \left(\frac{100 - \text{avg\% moisture by volume}}{100}\right)$$

$$= \frac{13.95\ (100 - 7.9)}{100}$$

$$= 12.86\ (\text{dscf}_{70})$$

2. From the psychrometric chart, gas with a wet-bulb temperature of 105°F and a dry-bulb temperature of 106°F contains 0.0508 pound of water per pound of dry air.

Then

$$\%\ \text{moisture by volume} = \frac{\left(\frac{\text{lb } H_2O/\text{lb dry air}}{18}\right) \times 100}{\left(\frac{\text{lb } H_2O/\text{lb dry air}}{18} + \frac{1}{30.4}\right)}$$

where 30.4 is the average molecular weight of the flue gas.

$$= \frac{(0.00282) \times 100}{(0.00282 + 0.0329)}$$

$$= 7.9\%$$

3. To calculate the dust loading use the formula

$$\text{Dust loading, gr/dscf}_{70} = \frac{\text{gm collected} \times 15.43}{\text{Vol. of gas, dscf}_{70}}$$

$$= \frac{0.005 \times 15.43}{12.86}$$

$$= 0.0060 \text{ gr/dscf}_{70}$$

4. To convert the weight of sulfur caught in the peroxide bottles into its equivalent volume of SO_2, divide the weight of the sulfur by the gram molecular weight of sulfur and multiply the quotient by the mol volume (in liters) divided by 28.32 (the number of liters per ft^3).

$$\text{Vol. } SO_2 \text{ sampled} = \frac{\text{Sample wt}}{\text{gm mol wt of S}} \times \frac{22.4}{28.32}$$

$$= \frac{0.33}{32.06} \times 0.791$$

$$= 0.008142$$

To convert the volume of SO_2 sampled to ppm in the exit gas, multiply the volume by 10^6 and divide by the combined volume of SO_2 plus exit gas.

$$SO_2 \text{ in exit gas} = \frac{0.008142}{0.008142 + 12.86}$$

$$= 633 \text{ ppm}$$

Sample Calculation Sheet for

Ammonia in Exit Flue Gas

Test Data

Test No.....................................RST-15
Date 2/26/71
Sample period...............................11:00 a.m. - 12:00 noon
Dry test meter readings.............
  Total volume through meter, ft^3.........7.0
  Temperature of meter, °F..............58.0
  Vacuum on meter, in Hg.................3.0

Wet-bulb temp. exit scrubber, °F 105
Dry-bulb temp. exit scrubber, °F 106

NH_3 caught in water during sampling, gm 0.01037

Calculations

1. To convert the volume of gas from meter conditions to dry standard cubic feet at atmospheric pressure and 70°F, use the formulas below.

$$V_1 = \frac{(29.92 - 3.0)(7.0)(460 + 70)}{(460 + 58)(29.92)}$$

$$= 6.44 \text{ ft}^3 \text{ at } 70°\text{F}$$

2. From the psychrometric chart, gas with a wet-bulb temperature of 105°F and a dry-bulb temperature of 106°F contains 0.0508 pound of water per pound of dry air.

Then

$$\% \text{ moisture by volume} = \frac{\left(\frac{\text{lb } H_2O/\text{lb dry air}}{18}\right) \times 100}{\left(\frac{\text{lb } H_2O/\text{lb dry air}}{18} + \frac{1}{30.4}\right)}$$

$$= \frac{(0.00282) \times 100}{(0.00282 + 0.0329)}$$

$$= 7.9\%$$

3.

$$V_{dry} = V_{wet} \left(\frac{100 - \% \text{ moisture}}{100}\right)$$

$$= 6.44 \left(\frac{92.1}{100}\right)$$

$$= 5.92 \text{ dscf}_{70}$$

4. To convert the weight of ammonia caught in the sample into its equivalent volume, divide the weight by the gram molecular weight of ammonia and multiply the quotient by the mol volume (22.4 liters) divided by the liters per ft^3 (28.32).

$$\text{Vol. } NH_3 = \frac{0.01037}{18} \times \frac{22.4}{28.32}$$
$$= 0.000459 \text{ ft}^3$$

To convert this volume to ppm in the exit gas, multiply the volume by 10^6 and divide by the combined volume of NH_3 plus exit gas.

$$\text{ppm } NH_3 = \frac{0.000459 \times 10^6}{0.000459 + 6.44}$$

$$= 71 \text{ ppm}$$

APPENDIX E - SAMPLE CALCULATIONS

These calculations were made using Johnstone's equations for the ammonia-sulfur dioxide-water system as presented in "Sulfur Oxide Removal from Power Plant Stack Gas"(19).

Typical Chemical Analysis of a Forward Feed

Solution for Pilot Plant No. 1

Sulfite sulfur ($SO_3^=$ as S)	21.33 gm/1
Bisulfite sulfur (HSO_3^- as S)	17.96 gm/1
Sulfate sulfur ($SO_4^=$ as S)	100.43 gm/1
Total	139.72 gm sulfur/1

pH - 6.2
Specific gravity - 1.248

Mols of Sulfur/Liter

Gm sulfur/1/molecular weight of sulfur = mol of sulfur/1
Sulfite sulfur = 21.33/32 = 0.67 mols/1
Bisulfite sulfur 17.96/32 = 0.56 mols/1
Sulfate sulfur 100.43/32 = 3.14 mols/1

Total Grams of Salt/Liter

Mols sulfur x molecular weight of salt = gm of salt/1
Sulfate sulfur 0.67 x 116 = 77.7 gm $(NH_4)_2SO_3$/1
Bisulfite sulfur 0.56 x 99 = 55.4 gm NH_4HSO_3/1
Sulfate sulfur 3.14 x 132 = 414.5 gm $(NH_4)_2SO_4$/1

Total salt = 547.6 gm/1

(Total SO_2) Mols of SO_2/Liter as

Sulfite and Bisulfite

SO_2 as Sulfite

Mols SO_2/1 as sulfite = mols sulfite sulfur/1 x 1.0
= 0.67 x 1.0
= 0.67 mols

SO_2 as Bisulfite

Mols SO_2/1 as bisulfite = mols bisulfite sulfur/1 x 1.0
= 0.56 x 1.0
= 0.56 mols

Total SO_2

Total SO_2 = SO_2 as sulfite + SO_2 as bisulfite
= 0.67 + 0.56
= 1.23 mols/l

(Active NH_3) Mols of NH_3/Liter as Sulfite and Bisulfite

NH_3 as Sulfite

Mols NH_3/l as sulfite = mols sulfite sulfur/l x 2.0
= 0.67 x 2.0
= 1.34 mols/l

NH_3 as Bisulfite

Mols NH_3/l as bisulfite = mols bisulfite sulfur/l x 1.0
= 0.56 x 1.0
= 0.56 mol/l

Active NH_3

Active NH_3 = NH_3 as sulfite + NH_3 as bisulfite
= 1.34 + 0.56
= 1.90 mols/l

(Total NH_3) Mols of NH_3/Liter as Sulfite, Bisulfite, and Sulfate

NH_3 as Sulfate

Mols NH_3/l as sulfate = mols sulfate/l x 2.0
= 3.14 x 2.0
= 6.28 mols/l

Total NH_3

Total NH_3 = NH_3 as sulfite + NH_3 as bisulfite + NH_3 as sulfate
= 1.34 + 0.56 + 6.28
= 8.18 mols/l

(Reaction Water) Grams H_2O/Liter Combined with SO_2 and NH_3

$$2NH_3 + SO_2 + H_2O \longrightarrow (NH_4)_2SO_3$$
$$NH_3 + SO_2 + H_2O \longrightarrow NH_4HSO_3$$
$$2NH_3 + SO_2 + H_2O + 1/2O_2 \longrightarrow (NH_4)_2SO_4$$

Reaction Water in Sulfite (Grams H_2O/l)

Reaction water ($SO_3^{=}$) = mols SO_2 as sulfite x 1.0 x 18 $\frac{\text{gm } H_2O}{\text{gm mol}}$
= 0.56 x 1.0 x 18
= 10.1 gm/l

Reaction Water in Bisulfite (Mols $H_2O/1$)

$$\text{Reaction water } (HSO_3^-) = \text{mols } SO_2 \text{ as bisulfite} \times 1.0 \times 18 \ \frac{\text{gm } H_2O}{\text{gm mol}}$$
$$= 0.67 \times 1.0 \times 18$$
$$= 12.1 \text{ gm/1}$$

Reaction Water in Sulfate (Mols $H_2O/1$)

$$\text{Reaction water } (SO_4^=) = \text{mols sulfate sulfur} \times 1.0 \times 18 \ \frac{\text{gm } H_2O}{\text{gm mol}}$$
$$= 3.14 \times 1.0 \times 18$$
$$= 56.5 \text{ gm/1}$$

(Free Water) Grams H_2O/Liter – Unreacted

$$\text{Free water} = (\text{Specific gravity} \times 1000) - \text{total salt gm/1}$$
$$= (1.248 \times 1000) - 547.6$$
$$= 1248 - 547.6$$
$$= 700.4 \text{ gm/1}$$

C Value (Mols Total NH_3/100 Mols H_2O)

$$C = \frac{(\text{mols total } NH_3)(1800)}{(\text{free water}) + [\text{reaction water } (SO_3^=) + \text{reaction water } (HSO_3^-) + \text{reaction water } (SO_4^=)]}$$

$$C = \frac{8.18\ (1800)}{(700.4) + (10.1 + 12.1 + 56.5)}$$

$$C = \frac{14,724}{700.4 + 78.7} = \frac{14,724}{779.1}$$

$$C = \underline{18.9 \text{ mols total } NH_3/100 \text{ mols } H_2O}$$

C_A Value (Mols Active NH_3/100 Mols H_2O)

The method used for calculating the C_A value was altered after a thorough review of Johnstone's data (3). The difference in the two methods used was centered around the definition of "100 mols of water." Method No. 1 defines it as the free water + the reaction water used in forming $(NH_4)_2SO_3$ and NH_4HSO_3 (1 mol of H_2O used per mol of S). Method No. 2 defines it as the free water + the reaction water used in forming $(NH_4)_2SO_3$, NH_4HSO_3, and $(NH_4)_2SO_4$ (1 mol of H_2O used per mol of S). All the values reported under pilot plant No. 1 were calculated by using method No. 1 and all values for pilot plant No. 2 were calculated by using method No. 2.

Method No. 1 (C_A')

$$C_A' = \frac{(\text{mols active } NH_3)\ 1800}{(\text{Free water}) + [\text{Reaction water } (SO_3^=) + \text{Reaction water } (HSO_3^-)]}$$

$$C_A' = \frac{(1.90)(1800)}{700.4 + (10.1 + 12.1)}$$

$$C_A' = \frac{3420}{700.4 + 22.2} = \frac{3420}{712.6}$$

C_A' = $\underline{4.73 \text{ mols active } NH_3/100 \text{ mols } H_2O}$

Method No. 2 (C_A)

$$C_A = \frac{(\text{mols active } NH_3)\ 1800}{(\text{free water}) + [\text{reaction water } (SO_3^=) + \text{reaction water } (HSO_3^-) + \text{reaction water } (SO_4^=)]}$$

$$C_A = \frac{(1.90)(1800)}{700.4 + (10.1 + 12.1 + 56.5)}$$

$$C_A = \frac{3420}{700.4 + 78.7} = \frac{3420}{779.1}$$

C_A = $\underline{4.39 \text{ mols active } NH_3/100 \text{ mols } H_2O}$

A Value (Mols $(NH_4)_2SO_4$/100 Mols H_2O)

$$A = \frac{(\text{mols sulfate sulfur/l})(1800)}{(\text{free water}) + [\text{reaction water } (SO_3^=) + \text{reaction water } (HSO_3^-) + \text{reaction water } (SO_4^=)]}$$

$$A = \frac{(3.14)(1800)}{700.4 + 78.7}$$

$$A = \frac{5652}{779.1}$$

A = 7.26 mols $(NH_4)_2SO_4$/100 mols H_2O

S Value (Mols SO_2/100 Mols H_2O)

$$S = \frac{(\text{total } SO_2,\ \text{mols/l})(1800)}{(\text{free water}) + [\text{reaction water } (SO_3^=) + \text{reaction water } (HSO_3) + \text{reaction water } (SO_4^=)]}$$

$$S = \frac{(1.23)(1800)}{700.4 + 10.1 + 12.1 + 56.5)}$$

$$S = \frac{2214}{779.1}$$

S = 2.84 mols SO_2/100 mols H_2O

S/C_A Ratio (Mols SO_2/Mols Active NH_3)

$$S/C_A = (\text{total } SO_2)(\text{active } NH_3)$$

$$S/C_A = \frac{1.23}{1.90}$$

$$S/C_A = 0.65$$

SO_2 Vapor Pressure of Absorber Liquor (mm Hg) at 125°F

$$SO_2 \text{ vapor pressure} = P_{SO_2} = M\,\frac{(2S-C+2A)^2}{(C-S-2A)}$$

$$\text{Where } \log M = 5.865 - \frac{2369}{\text{liquor temperature, °K}}$$

$$\log M = 5.865 - \frac{2369}{324.7}$$

$$\log M = -1.431$$

$$M = 0.0371$$

$$P_{SO_2} = 0.0371\,\frac{[(2 \times 2.84) - 18.9 + (2 \times 7.26)]^2}{[18.9 - 2.84 - (2 \times 7.26)]}$$

$$P_{SO_2} = \frac{0.0371\,[1.30]^2}{[1.54]} = \frac{0.0371[1.69]}{[1.54]}$$

$$P_{SO_2} = 0.0407 \text{ mm Hg}$$

NH_3 Vapor Pressure of Absorber Liquor (mm Hg) at 125°F

$$NH_3 \text{ vapor pressure} = P_{NH_3} = \frac{N\,C(C-S-2A)}{2S-C+2A}$$

$$\text{Where } \log N = 13.680 - \frac{4987}{\text{Liquor temp., °F}}$$

$$\log N = 13.680 - \frac{4987}{324.7}$$

$$\log N = -\,1.679$$

$$N = 0.0209$$

$$P_{NH_3} = \frac{(0.0209)(18.9)[18.9 - 2.84 - (2 \times 7.26)]}{[(2 \times 2.84) - 18.9 + (2 \times 7.26)]}$$

$$P_{NH_3} = \frac{(0.0209)(18.9)(1.54)}{(1.30)} = \frac{(0.609)}{(1.30)}$$

$$P_{NH_3} = 0.468 \text{ mm}$$

H_2O Vapor Pressure of Absorber Liquor (mm Hg) at 125°F

$$H_2O \text{ vapor pressure} = P_{H_2O} = P_W \left[\frac{100}{100 + C + S}\right]$$

Where P_W = vapor pressure of pure water at temperature involved

$$P_{H_2O} = 97.20 \left[\frac{100}{100 + 18.9 + 2.84}\right]$$

$$P_{H_2O} = 97.2 \left[\frac{100}{119.74}\right]$$

$$P_{H_2O} = 79.84 \text{ mm Hg}$$

APPENDIX F – CORROSION DATA

Corrosion

Corrosion tests were made on metallic and nonmetallic materials in pilot plant No. 1 during the following periods of pilot-plant operation: period A, 109 hours of operating time using the sieve-tray (Sly) absorber; period B, 897 hours of operating time using the marble-bed absorber; and period C, 339 hours of additional operating time using the marble-bed absorber.

The test specimens were installed in the flue gas ducts, the absorber, the recirculation tanks, and the pipes for circulating liquor. Table 12 lists the tradename, base type, and manufacturer of each nonmetallic material tested. Tables 13 through 16 give information about the location of test specimens, exposure conditions, materials tested, and evaluation of test materials exposed.

TABLE 12

NONMETALLIC MATERIALS TESTED IN THE PILOT PLANT FOR REMOVAL OF SULFUR DIOXIDE BY THE AMMONIA-ABSORPTION PROCESS

Trade name	Base type	Manufacturer
Atlac 382-05A	Propoxylated bisphenol-A fumarate polyester resin with fiber glass reinforcing	Atlas Chemical Industries, Inc. Chemical Division Wilmington, Delaware
Atlac 711-05A	Polyester resin containing 5% antimony with fiber glass reinforcing	Atlas Chemical Industries, Inc. Chemical Division Wilmington, Delaware
Heresite P-403 + L-66	Thermosetting phenol-formaldehyde resinous coating applied on carbon steel	Heresite and Chemical Company Manitowac, Wisconsin
Hetron 197	Styrenated polyester; Durez Division	Hooker Chemical Corporation New York, New York
Hetron 197-3	Styrenated polyester modified for hand or spray application	Hooker Chemical Corporation New York, New York
Lucoflex	Polyvinyl chloride, rigid	American Lucoflex, Inc. New York, New York
Polypropylene	Polypropylene, rigid	American Viscose Corporation Philadelphia, Pennsylvania
1580 rubber	Butyl, Flexible	The Goodyear Tire and Rubber Company Tank Lining Division Akron, Ohio
Neoprene	Chloroprene polymer, flexible	E. I. DuPont de Nemours and Company Wilmington, Delaware
Viton	Copolymer of hexofluopropylene and vinylidene fluoride	E. I. DuPont de Nemours and Company

TABLE 13

CORROSION TESTS CONDUCTED IN THE FLUE GAS DUCTS OF THE PILOT PLANT FOR REMOVAL OF SULFUR DIOXIDE BY THE AMMONIA-ABSORPTION PROCESS

Test period	A	B	C	A	B	C
Number of pilot-plant runs	6	142	33	6	106	33
Operating time, hr	29	897	339	29	537	339
Idle time, hr	979	7671	1677	979	7095	1677
Location of specimens	Gas to cyclone			Gas from cyclone to cooler		
Gas						
Temperature, °F	320	305	309	319	295	292
Flow rate, cfm	4000	4000	3000	4000	4000	4000
Velocity, ft/sec	60	60	60	60	60	60
Composition, % by volume						
SO_2	0.25	0.25	0.25	0.25	0.25	0.25
SO_3	0.03	0.03	0.03	0.003	0.003	0.003[a]
CO_2	12	12	12	-	-	12
N_2	75	75	75	-	-	75
O_2	5	5	5	-	-	5
H_2O	8	8	8	-	-	8
Fly ash, gr/std cu ft	5.0	5.0	5.0	1.2	1.2	1.2
Corrosion rate of metal specimen, mils/yr						
AISI stainless steel						
Type 202, weld Type 316	-	-	3	-	-	3[b]
Type 410	-	-	5	-	-	17
Haynes alloy B6	17	4	3	1	1	< 1
Type 502 steel	49	28	17	-	-	21
Mild steel A-283	54	27	14	534	202	80
Condition of nonmetallic specimen[c, d]						
Atlac 382-05A	Fair	Poor	-	-	-	-
Atlac 711-05A	Fair	Poor	-	-	-	-
Heresite P-403 + L-66	Poor[e]	Poor[e]	-	-	-	-
Hetron 197	Fair	Poor	-	-	-	-
Hetron 197-3	Fair	Poor	-	-	-	-
Polypropylene	Fair	-	-	-	-	-
Lucoflex-rigid polyvinyl chloride	-	-	-	-	-	-
1580 rubber-butyl	-	-	-	-	-	-
Neoprene	-	-	-	-	-	-
Viton	-	Fair	-	-	-	-

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[a] Ammonia was added to neutralize part of sulfur trioxide.

[b] Pitted to depth indicated.

[c] Evaluation was based on change (if any) that occurred during indicated test period; good, little or no change; fair, definite change, probably could be used; poor, failed, not suitable.

[d] Nonmetallics were not tested in the gas upstream of the absorber during test period B.

[e] Abrasion had cut through the 5-mil coating.

TABLE 14

CORROSION TESTS CONDUCTED IN THE RECIRCULATION TANKS OF THE PILOT PLANT FOR REMOVAL OF SULFUR DIOXIDE BY THE AMMONIA-ABSORPTION PROCESS

Test period	A	B	C	A	B	C	A	B	C	A	B	C
Number of pilot-plant runs	6	30	33	6	130	33	6	142	33	6	130	33
Operating time, hr	29	180	339	29	724	339	29	897	339	29	724	339
Idle time, hr	979	924	1677	979	7676	1677	979	7671	1677	979	7676	1677
Location of specimens in tank No.	F-1						F-2					
Exposed in	Liquid			Vapor			Liquid			Vapor		
	F-1L			F-1G			F-2L			F-2G		
Liquid in tanks												
Temperature, °F	129	121	125	129	121	125	129	116	121	129	116	121
pH	7.6	5.2–6.2	5.8	–	–	–	6.7	5.6–6.8	6.2	–	–	–
Retention time in tank, min	10.6	6.5	8.5	–	–	–	10.6	9.9	10	–	–	–
Pressure, psi	–0.5	–0.5	–0.5	–0.5	–0.5	–0.5	–0.5	–0.5	–0.5	–0.5	–0.5	–0.5
Composition of vapor, % by volume[c]												
NH_3	–	–	–	0.04	0.04	0.02	–	–	–	0.01	0.01	0.03
SO_2	–	–	–	0.00	0.06	0.06	–	–	–	0.00	0.00	0.05
Composition of liquor, % by wt												
NH_4HSO_3	0.5	24.6	15.2	–	–	–	0.07	19.5	5.1	–	–	–
$(NH_4)_2SO_3$	7.6	3.9	9.5	–	–	–	1.7	5.1	7.4	–	–	–
$(NH_4)_2SO_4$	5.6	5.6	27.0	–	–	–	3.4	5.3	12.1	–	–	–
Solids	2.4	2.4	2.4	–	–	–	1.6	1.6	1.6	–	–	–
Corrosion rate of metal specimens, mils/yr												
AISI stainless steel												
Type 202, weld Type 308	–	–	< 1	–	–	–	–	–	< 1	–	–	< 1
Type 304L, weld Type 304L	1	< 1	< 1	2	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Type 316L, weld Type 316L	1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Type 410	–	–	–	–	–	–	–	–	–	–	–	P. 9[d]
Durimet 20	1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Mild steel A-285	393	1430	413	650	325	322	1410	345	424	532	226	150
Condition of nonmetallic specimens[e]												
Atlac 382-05A	Good	Good	Good	Good	Good	Good	Good	Good	Good[f]	Good	Good	Good[f]
Atlac 711-05A	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Heresite P-403 + L-66	Good	Good	Good	Good	Good	Good	Good	–	Good	Good	–	–
Hetron 197	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Hetron 197-3	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Polypropylene	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Lucoflex (PVC)	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
1580 butyl rubber, Goodyear	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Neoprene	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Viton	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Natural gum rubber	–	–	Good	–	–	Good	–	–	Good	–	–	Good

TABLE 14 (CONTINUED)

Test period (current)	B	C	B	C	A	B	C
Number of pilot-plant runs	156	33	144	33	6	130	33
Operating time, hr	794	339	796	339	29	724	339
Idle time, hr	8902	1677	8752	1677	979	7676	1677
Location of specimens in tank No.	F-3[a]				F-5[b]		
Exposed in	Liquid		Vapor		Vapor		
Identification No.	F-3L		F-3G		F-5G		
Liquid in tanks							
Temperature, °F	116	120	116	120	90	70	80
pH	5.0-7.0	5.9	–	–	–	–	–
Retention time in tank, min.	–	10	–	–	–	–	–
Pressure, psi	−0.5	−0.5	−0.5	−0.5	–	−0.5	–
Composition of vapor, % by volume[c]							
NH_3	–	–	–	0.02	0.02	0.025	0.04
SO_2	–	–	–	0.04	0.00	0.000	0.04
Composition of liquor, % by wt							
NH_4HSO_3	17.5	3.8	–	–	–	–	–
$(NH_4)_2SO_3$	3.1	2.4	–	–	–	–	–
$(NH_4)_2SO_4$	5.2	5.8	–	–	–	–	–
Solids	–	1.0	–	–	–	–	–
Corrosion rate of metal specimens, mils/yr							
AISI stainless steel							
Type 202, weld Type 308	–	< 1	–	–	–	–	–
Type 304L, weld Type 304L	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Type 316L, weld Type 316L	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Type 410	–	–	–	P. 14[d]	–	–	–
Durimet 20	< 1	< 1	< 1	< 1	–	–	–
Mild steel A-285	361	312	209	91	381	261	215
Condition of nonmetallic specimens[e]							
Atlac 382-05A	Good	Good[f]	Good	Good	–	–	–
Atlac 711-05A	Good	Good	Good	Good	–	–	–
Heresite P-403 + L-66	–	–	–	–	–	–	–
Hetron 197	Good	Good	Good	Good	–	–	–
Hetron 197-3	Good	Good	Good	Good	–	–	–
Polypropylene	Good	Good	–	Good	–	–	–
Lucoflex (PVC)	Good	Good	Good	Good	Good	Good	Good
1580 butyl rubber, Goodyear	Good	Good	Good	Good	Good	Good	Good
Neoprene	Good	Good	Good	Good	Good	Good	Good
Viton	Good	Good	Good	Good	Good	Good	Good
Natural gum rubber	–	Good	–	Good	–	–	Good

---

[a] During test A, specimens were not exposed in the liquid or the vapor in tank F-3.

[b] Specimens were immersed about half the exposure period because the level fluctuated in the storage tank.

[c] Values for percent by volume were estimated.

[d] Specimen was pitted during the test period to depth in mils indicated.

[e] Evaluation "good" indicates that little (if any) change occurred in material of construction (see footnote "f") during test.

[f] The resin used to seal edges of disk failed apparently because of breakage; however, the disk was in good condition.

TABLE 15

CORROSION TESTS CONDUCTED IN VERTICAL SECTIONS OF PIPES CIRCULATING LIQUOR TO THE ABSORBER AT THE PILOT PLANT FOR REMOVAL OF SULFUR DIOXIDE BY THE AMMONIA-ABSORPTION PROCESS

Test period	A	B	C	A	B	C
Number of pilot-plant runs	6	106	33	6	106	33
Operating time, hr	29	537	339	29	537	339
Idle time, hr	979	7095	1677	979	7095	1677
Test specimen located in	First pipe			Second pipe		
Identification No.	[illegible]-1			J-2		
Liquor						
Temperature, °F	129	121	121	129	116	124
pH	7.6	5.2-6.6	5.8	6.7	5.6-6.8	6.2
Velocity, ft/sec	0.61	1.3	1.3	0.60	0.87	0.9
Flow rate, gpm	14	30	30	13.8	19.8	20
Pressure, psi	20	20	20	20	20	20
Composition, % by wt						
NH_4HSO_3	0.5	2.6	15.2	0.07	19.5	5.1
$(NH_4)_2SO_3$	7.6	3.9	9.5	1.7	5.1	7.4
$(NH_4)_2SO_4$	5.6	5.6	27.0	3.4	5.3	12.1
Solids	2.4	2.4	2.4	1.6	1.6	1.6
Corrosion rate of metal specimen, mils/yr						
AISI stainless steel						
Type 304L, weld Type 316L	< 1	2	< 1	1	< 1	< 1
Type 316L, weld Type 316L	< 1	1	2	< 1	< 1	< 1
Type 410	-	-	9[a]	-	-	5[a]
Durimet 20	< 1	3	1	< 1	< 1	< 1
Mild steel A-283	471	227	370	-	-	-
Condition of nonmetallic specimens[b]						
Heresite P-403 + L-66	Poor[c]	Good	Poor[c]	-	-	-
Lucoflex	Fair	Good	Good	-	-	Good
1580 butyl rubber, Goodyear	Fair	Good	Good	Fair	-[d]	-
Neoprene	-[d]	Good	Good	-	-	-
Viton	-[d]	Good	Good	Fair	-[d]	-
Polypropylene	-	-	-	-	-	Good

[a] Specimen pitted during test period to depth in mils indicated.

[b] Evaluation was based on change, if any, that occurred during indicated test period: good, little or no change; fair, definite change probably could be used; poor, failed or severely damaged.

[c] Abrasion cut through the 5-mil coating.

[d] Specimen lost.

TABLE 16

CORROSION TESTS CONDUCTED IN THE PILOT PLANT FOR THE REMOVAL OF SULFUR DIOXIDE BY THE AMMONIA-ABSORPTION PROCESS

Test period	A	B	C	A	B	C	A	B	
Number of pilot-plant runs	22	106	33	22	106	33	22	106	3
Operating time, hr	109	537	339	109	537	339	109	537	33
Idle time, hr	1667	5151	1677	1667	5151	1677	1667	5151	167
Location of specimens above absorber	First stage			Third stage			Mist eliminator		
Gas-liquor mixture									
Temperature, °F	128	112	128	129	111	120	129	110	12
Velocity, ft/sec	7.0	7.0	6.4	7.0	7.0	6.4	7.0	7.0	6.
Flow rate, cfm	3000	3000	2700	3000	3000	2700	3000	3000	270
Pressure, psi	-0.5	-0.5	-0.5	-0.6	-0.6	-0.6	-0.7	-0.7	-0.
Composition of vapor, % by volume (estimated)									
SO_2	0.13	0.13	0.13	0.08	0.08	0.08	0.08	0.08	0.0
CO_2	12	12	12	12	12	12	12	12	1
N_2	69	69	69	69	69	69	69	69	6
O_2	5	5	5	5	5	5	5	5	
H_2O	14	14	14	14	14	14	14	14	1
Composition of liquor, % by wt									
NH_4HSO_3	16.7	23.5	15.2	14.2	18.6	3.8	-	-	-
$(NH_4)_2SO_3$	26.6	7.5	9.5	10.8	5.8	2.4	-	-	-
$(NH_4)_2SO_4$	3.2	5.1	27.0	6.2	4.2	5.8	-	-	-
Solids	2.4	2.4	2.4	1.6	1.6	1.0	-	-	-
pH	6.9	5.2-6.6	5.6	6.2	5.2-6.6	5.8	-	5.0-6.0	5.
Corrosion rate of metal specimens, mils/yr									
AISI stainless steel									
Type 202, weld Type 316	-	-	< 1[b]	-	-	1[b]	-	-	P. 1
Type 304L, weld Type 304L	< 1	< 1	1[b]	< 1	< 1	1[b]	< 1	< 1	P. 2
Type 316L, weld Type 316L	< 1	< 1	< 1[b]	< 1	< 1	< 1[b]	< 1	< 1	
Type 410	-	-	P. 7[a]	-	-	P. 6[a]	-	-	P. 2
Durimet 20	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	
Mild steel A-283	257	126	206	348	154	186	695	308	41
Condition of nonmetallic specimens[c]									
Atlac 382-05A	Good	Good	Good[d]	-	-	-	Good	Good[d]	Goo
Atlac 711-05A	Good	Good	Good	-	-	-	Good	Good	Goo
Heresite P-403 + L-66	Good	Good	Poor[e]	-	-	-	Good	Good	Goo
Hetron 197	Good	Good	Good	-	-	-	Good	Good	Goo
Hetron 197-3	Good	Good	Good	-	-	-	Good	Good	Goo
Polypropylene	Good	Good	Good	-	-	-	Good	Good	Goo
Lucoflex (PVC)	Good	Good	Good	-	-	-	Good	Good	Goo
1580 rubber (butyl), Goodyear	Good	Good	Good	-	-	-	Good	Good	Good
Neoprene	Good	Good	Good	-	-	-	Good	Good	Goo
Viton	Good	Good	Good	-	-	-	Good	Good	Good
Natural gum rubber	-	-	Good	-	-	-	-	-	Good

[a] Specimen pitted during test to indicated depth in mils.
[b] Stressed specimen showed no evidence of cracking.
[c] Evaluation was based on change (if any) that occurred during indicated test period. Good, little or no change; poor, failed or severely damaged.
[d] Resin used to seal edges of disk failed, apparently because of breakage.
[e] Abrasion had cut through the 5-mil coating.

APPENDIX G - GLOSSARY

A value	the mols of ammonium sulfate present per 100 mols of total water
C value	the mols of ammonia present in the form of ammonium sulfite, bisulfite, and sulfate (total ammonia) per 100 mols of total water
C_A value	the mols of ammonia present in the form of ammonium sulfite and bisulfite (active ammonia) per 100 mols of total water
C_A' value	the mols of ammonia present in the form of ammonium sulfite and bisulfite per 100 mols of total water'
Free water	the water of solution contained in the absorbing liquor
Reaction water	the water used in forming ammonium sulfite, bisulfite, and sulfate (1 mol of water used per 1 mol of S)
S value	the mols of SO_2 present in the form of ammonium sulfite and bisulfite per 100 mols of total water
S/C_A or S/C_A' value	a mol ratio of the SO_2 present as ammonium sulfite and bisulfite to the ammonia present as ammonium sulfite and bisulfite
Total water	the free water plus the reaction water (water of constitution) required when SO_2 and NH_3 react to form ammonium sulfite, bisulfite, and sulfate. One mol of water is consumed for each mol of SO_2 that reacts
Total water'	the free water plus the reaction water required when SO_2 and NH_3 react to form ammonium sulfite and bisulfite but not sulfate

Sample calculations using these terms are given in Appendix E.

APPENDIX H – CONVERSION FACTORS

To convert from English units	To metric units	Multiply by
cfm	m^3/min	0.028317016
°F	°C	(subtract 32 and multiply by 5/9)
Btu/lb(°F)	gm cal/gr(°C)	1
Btu/hr(ft^2)(°F)	gm cal/sec(cm^2)°C	0.00013562
inch	cm	2.54
grains/ft^3	grams/liter	0.00228834
gpm	liters/sec	0.0631
mol/min(ft^2)	mol/min(cm^2)	929.0341
psi	mm of Hg at 0°C	51.715
lb/hr	kg/hr	0.453
ft	meters	0.3048
gal/hr(ft^2)	liter/hr(m^2)	40.746
ft^3	liters	28.31625

APPENDIX I

STACK PLUMES—CONDENSED MOISTURE AND/OR OPAQUE POLLUTANTS*

Introduction

Before May 1973, the most troublesome problem encountered by TVA in developing the ammonia scrubbing - bisulfate regeneration process at their Colbert station in northwestern Alabama was the presence of an opaque plume in the flue gas released to the atmosphere. The objectionable portion of the plume is an aerosol of ammonia-based salt very difficult to remove from the flue gas. The opacity of the plume is dependent in part on the quantity of the salt aerosol and its size distribution. Plume opacity is also dependent, in part, on the number of moisture droplets of light scattering size which form on contact with humid, cold air. Opacity from "uncombined" water should not be included in determining whether overall plume opacity exceeds permissible specifications according to regulations (20). However, as Crocker (21) noted, the meaning of "uncombined" water may remain obscure for some time. Also opacity of an emission from a stationary source is estimated visually by a "qualified" observer. To quality as an observer a candidate must complete a smokereading course conducted by EPA or equivalent. This course, outlined in the Federal Register (20), does not qualify the observer to distinguish between light scattering water droplets and salt aerosols.

The situation outlined above suggested that objectionable salt aerosol plume formation and opacity cannot be studied quantitatively in the presence of a water plume. The purpose of this appendix is to consider factors influencing the formation of water plumes so that they can be avoided. As we shall see, water plumes can be avoided by reheating the scrubber exit gas before it is discharged from the stack. However, the important consideration is not the water plume that is eliminated but the non-aqueous plume that remains. In the absense of a water plume, scrubber liquor composition, temperature, etc., may be varied within acceptable process limitations to minimize or eliminate a non-aqueous plume. This is an important and often critical factor in development of a new process. It is also important that slip-streams from operating scrubbers be tested from time to time to determine whether any malfunctions have developed. To study non-aqueous plumes, water must be eliminated. This study outlines a method for estimating the temperature at the reheater exit to avoid a water plume from the stack. The method described is applicable generally to aqueous scrubbing systems vented to the atmosphere.

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* We would like to acknowledge the assistance of Dr. L. I. Griffin in the preparation of this appendix. Dr. Griffin was the ammonia scrubbing - bisulfate regeneration project officer for EPA at the time this study was made.

Factors Relating to Plume Formation

Water plumes are formed when the temperature of the mixture of flue gas and ambient air falls below the dew point temperature can be estimated by the procedure described below. The data required are the ambient air temperature and humidity along with the scrubber top stage composition, temperature, and pressure. In estimating the dew point temperature, mixing of the flue gas with ambient air is assumed to be adiabatic. Further it is assumed that the gas leaving the scrubber top stage is saturated with water vapor and contains no entrained liquid. Finally it is assumed that the molar heat capacities of air and flue gas are equivalent.

Derivation of Mathematical Relationship Limiting the Formation of Water Plumes

If the mixture of ambient air and flue gas at the stack exit is at its dew point, the conditions for Equation 1 are satisfied.

$$\frac{R \times vp_{AA} \times FRH + pp_S}{1 + R} = vp_{DP} \qquad \underline{\text{Equation 1}}$$

Where

R = mols of ambient air/mol of flue gas
vp_{AA} = vapor pressure of water at ambient air temperature, psia
FRH = factional relative humidity
pp_S = partial pressure of water vapor in flue gas at stack exit
vp_{DP} = vapor pressure of water at the dew point temperature of the gas mixture, psia

Substituting known values of parameters into Equation 1 allows for the determination of vp_{DP}. Subsequently, the dew point temperature, T_{DP}, can be read from steam tables relating vapor pressure and temperature.

Heat balance considerations consistent with the assumptions given earlier justify the following relationship:

$$RC_{pAA} (T_{DP} - T_{AA}) = C_{pFG} (T_{RE} - T_{DP}) \qquad \underline{\text{Equation 2}}$$

Where

R = mols of ambient air/mol of flue gas
$C_{pAA}=C_{pFG}$ = molar heat capacity of air and flue gas
T_{DP} = dew point temperature, °F
T_{AA} = temperature of ambient air, °F
T_{RE} = temperature of flue gas at reheater exit, °F

The relationship on page I-2, Equation 2, may be simplified as follows and the required reheat temperature of the flue gas, T_{RE}, may be calculated.

$$T_{RE} = R(T_{DP} - T_{AA}) + T_{DP} \qquad \text{Equation 3}$$

Discussion of Relationship Limitations and Implications

On hot dry days water plumes are not obtained; whereas, on cold humid days, plumes will be obtained unless the flue gas is reheated. Water plume formation boundaries, calculated from Equations 1 and 3, are shown in Figure 46 for a scrubber temperature of 120°F and an ambient air temperature of 40°F. The curves relate reheat exit gas temperature required to avoid a water plume to the mols of ambient air mixed with one mol of reheated flue gas. Curves are shown for relative humidities of ambient air ranging from zero to 90%. For relative humidities of less than 100%, the curves exhibit a maximum flue gas reheat temperature required to avoid a plume at any ambient-air-to-flue gas ratio.

More specifically, the water plume formation boundaries shown on Figure 46 form envelopes for the several humidities indicated. When reheated flue gas is discharged from the stack, it is mixed continuously with ever increasing quantities of air. For any ambient-air-to-flue-gas ratio, there is a calculable reheater exit temperature required to avoid the formation of a water plume. This required reheater exit gas temperature increases at first with the ratio of ambient air to flue gas. However, since the flue gas is mixed with ever increasing quantities of air, the air-to-flue-gas ratio will inevitably increase to and pass beyond the critical value requiring the maximum reheater exit gas temperature (see triangles, Figure 46) to avoid plume formation.

Thus, in predicting the formation of water plumes, the critical flue gas temperature should be used rather than some lower temperature. Reheater exit gas temperatures for zero water plume potential, or critical flue gas temperature, are related to ambient air temperatures in Figures 47 through 51. Each figure is for a single scrubber temperature starting with 120°F and increasing in 5°F increments to 140°F. Also, each figure shows curves for constant relative humidities ranging from zero to 90%.

Estimating Flue Gas Reheat Temperature to Avoid Formation of a Water Plume

How can these curves be used to estimate the reheater exit gas temperature required to avoid a water plume for a specific set of conditions? Assume that the flue gas is being scrubbed with an ammoniacal solution to remove SO_x. The scrubber top stage temperature and pressure are 127°F and 15.2 psia, respectively. Liquid composition on the top stage is consistent with C=4.0, S=3.2, and A=0.3 as defined by Johnstone (3). The ambient air temperature is 35°F and the relative humidity is 45%. What reheater exit gas temperature is required to avoid a water plume?

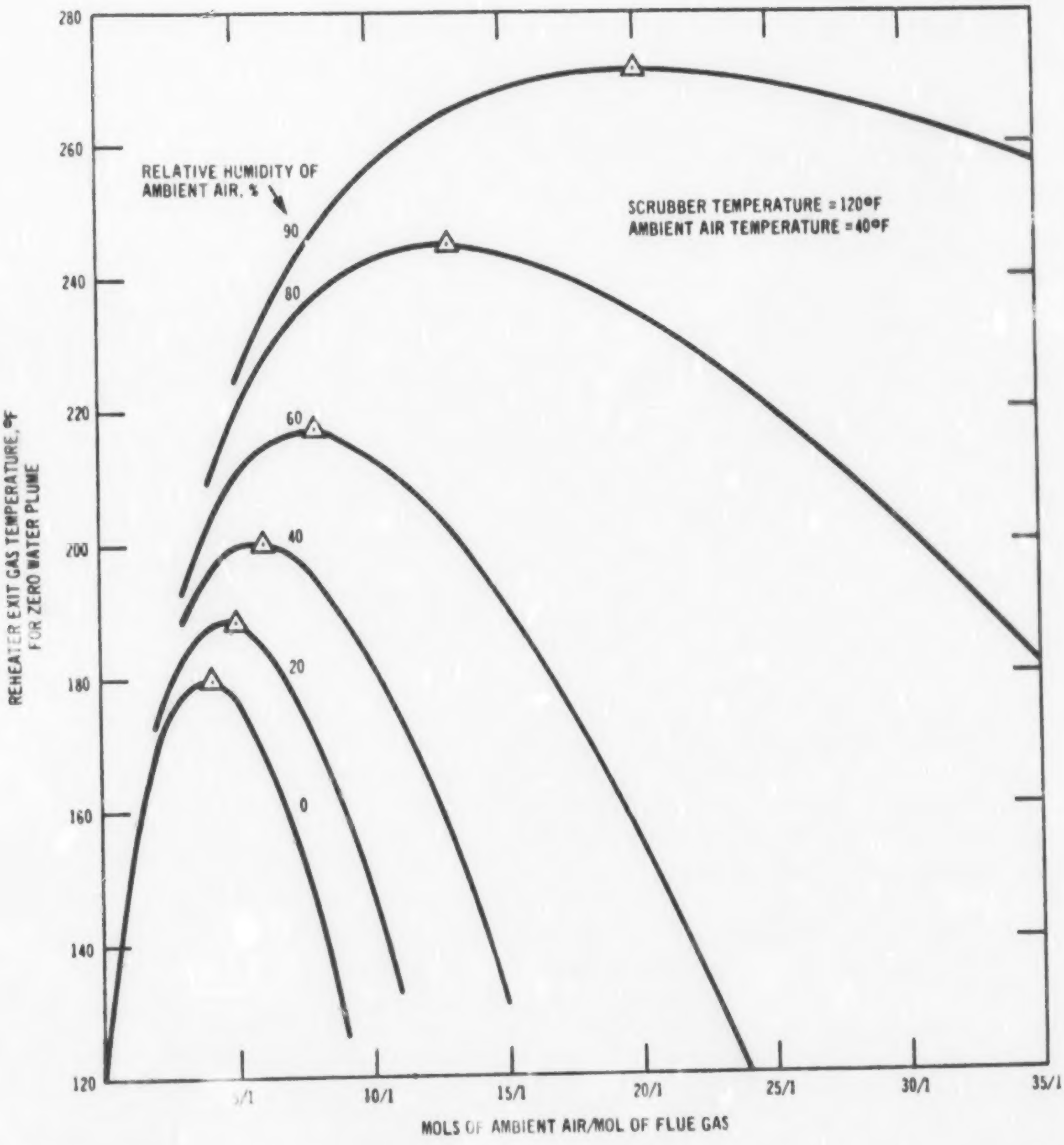

FIGURE 46

Water Plume Formation Boundaries

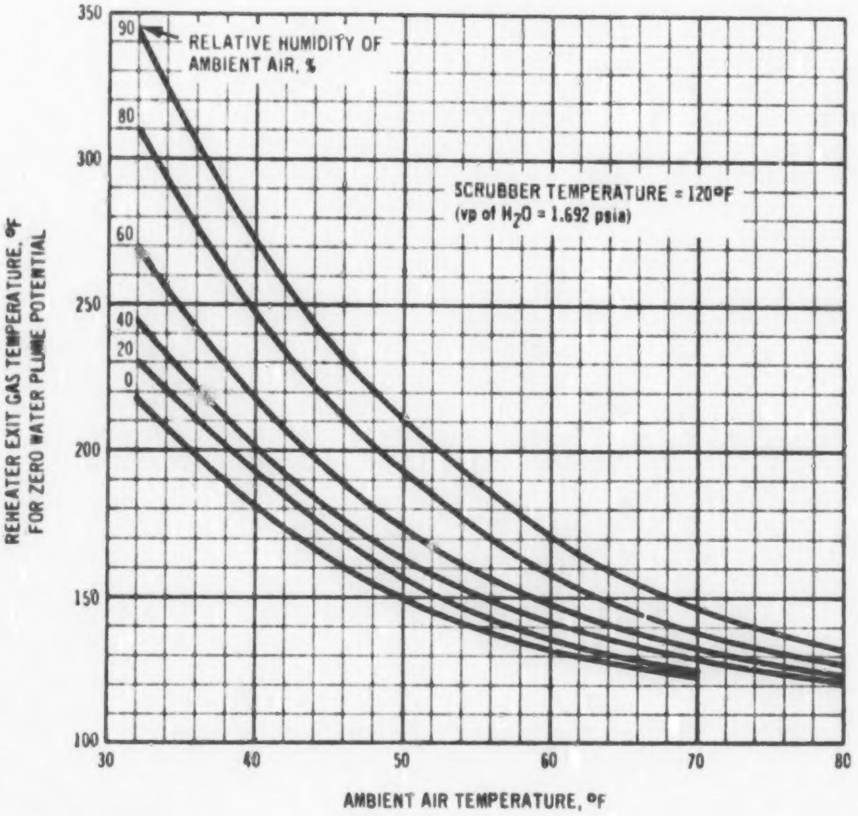

FIGURE 47

Relationship of Factors Governing

Formation of Water Plumes From Stacks

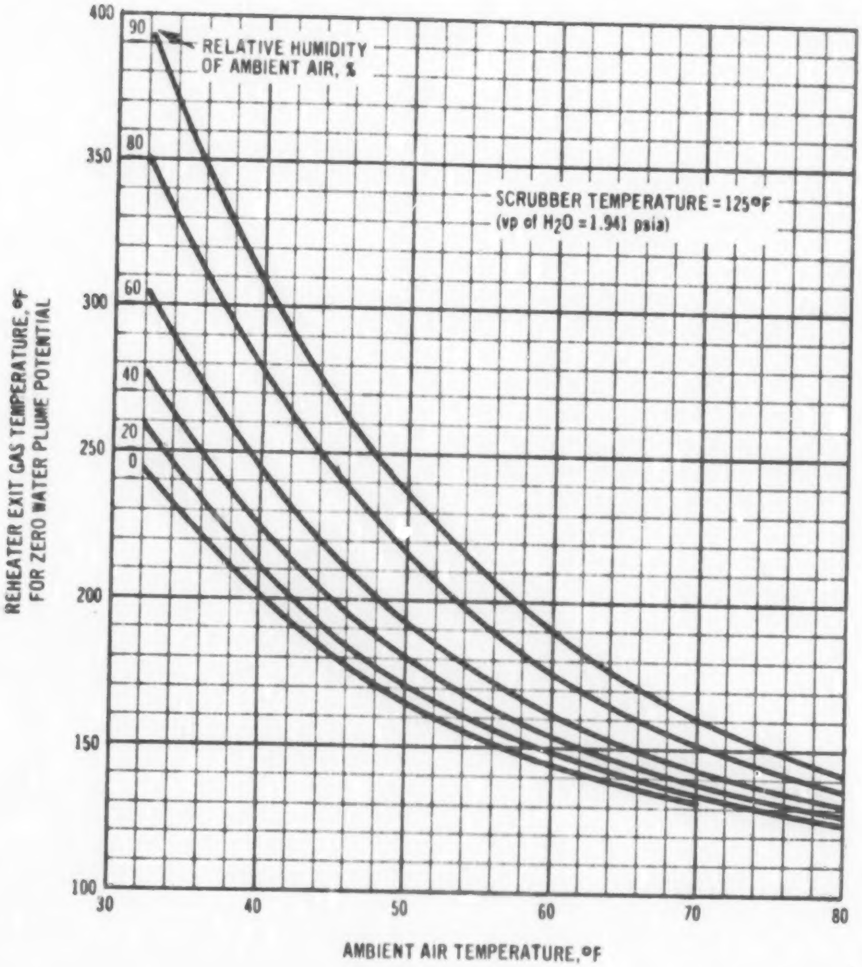

FIGURE 48

Relationship of Factors Governing Formation of Water Plumes From Stacks

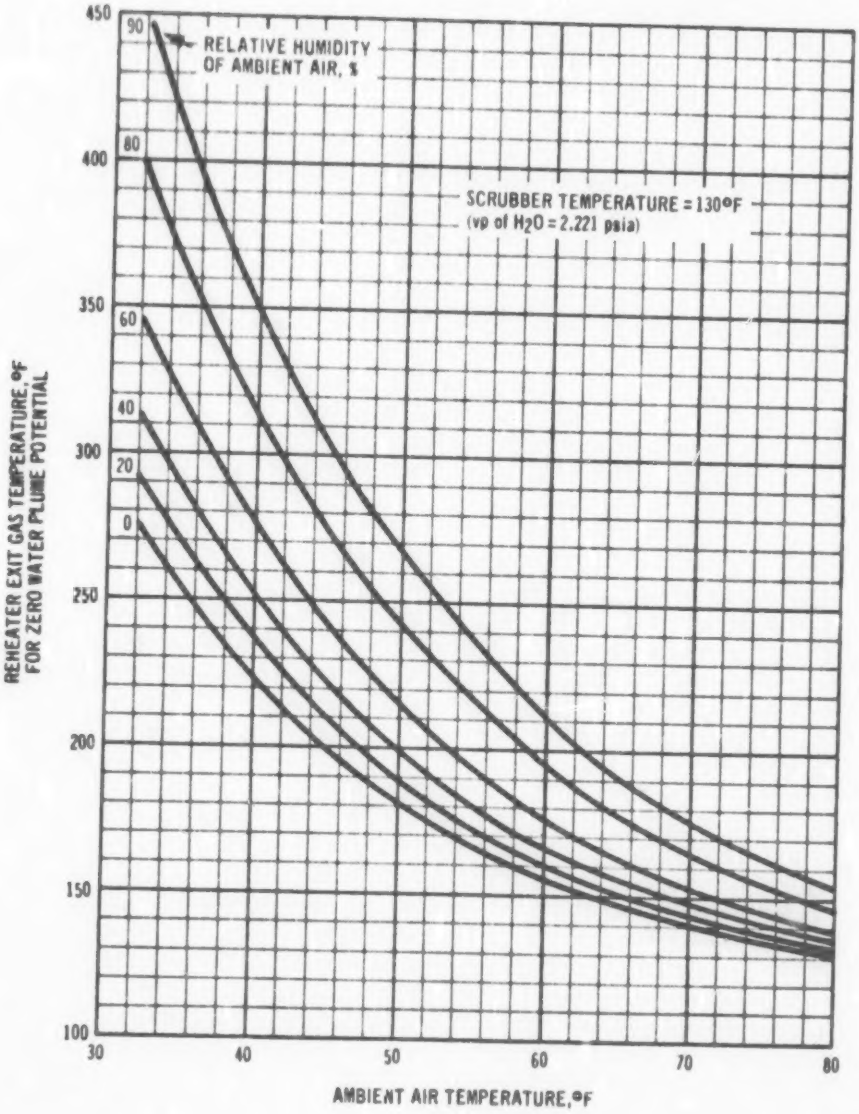

FIGURE 49

Relationship of Factors Governing

Formation of Water Plumes From Stacks

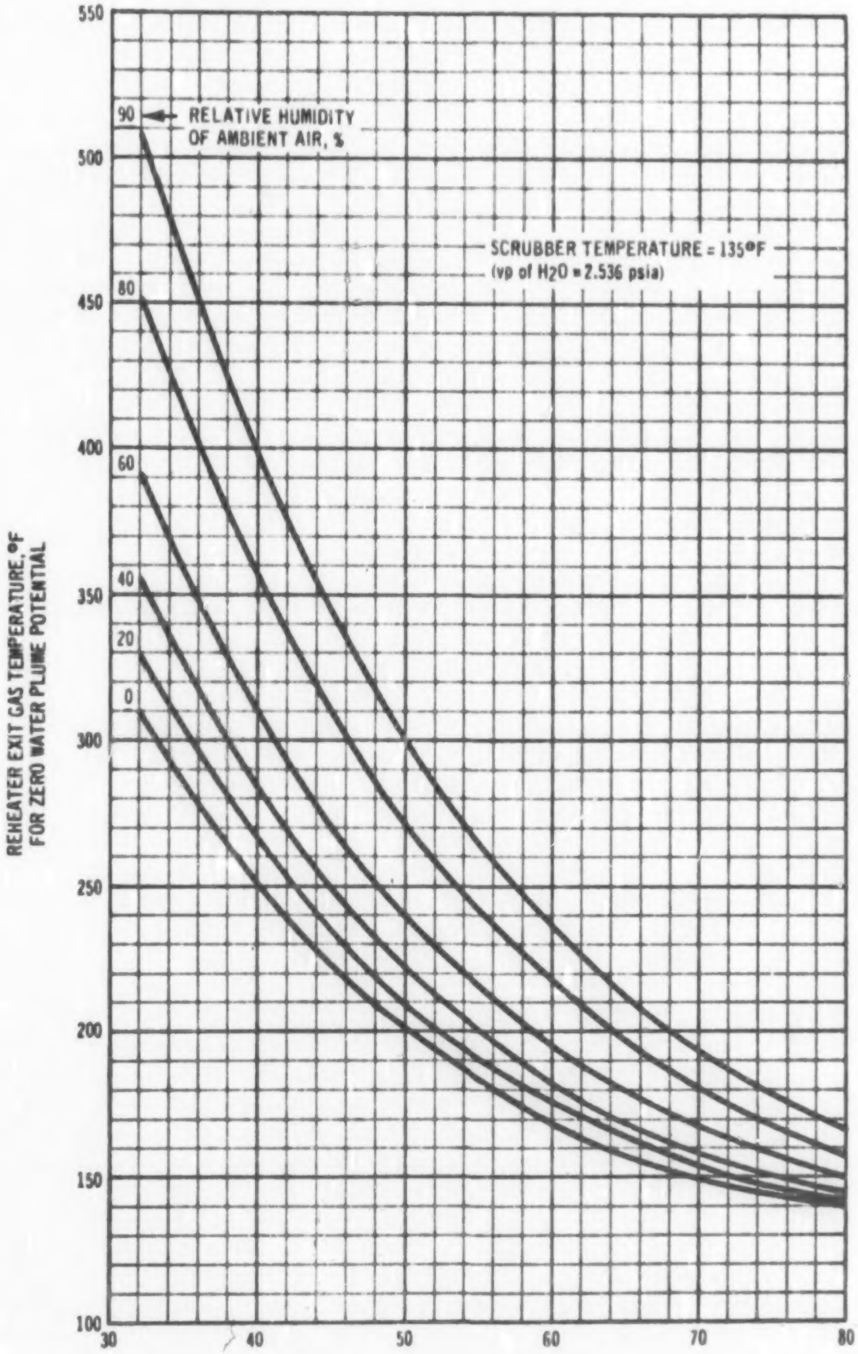

FIGURE 50

Relationship of Factors Governing

Formation of Water Plumes From Stacks

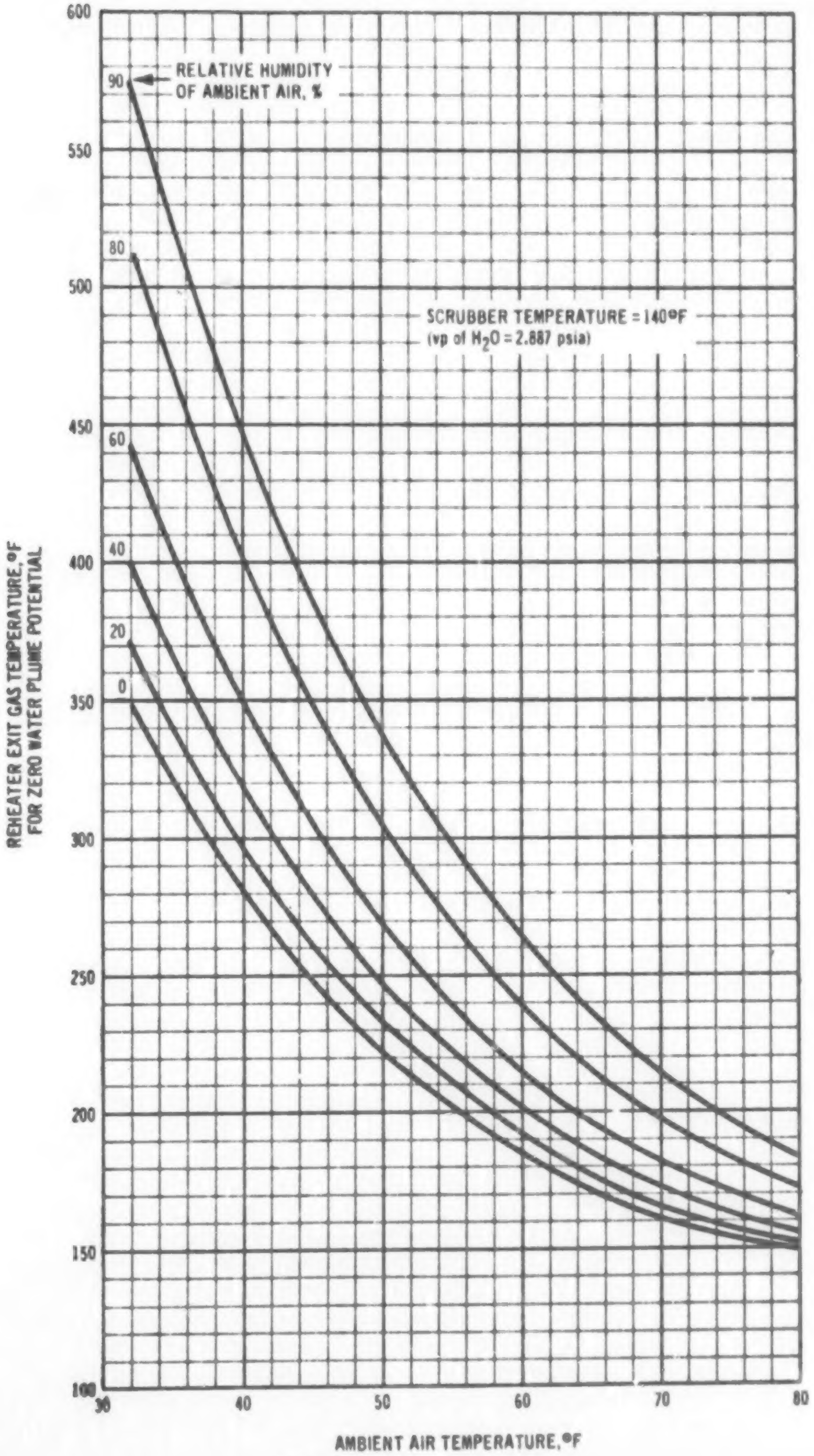

FIGURE 51

Relationship of Factors Governing Formation of Water Plumes From Stacks

At 127°F the vapor pressure of water is 2.049 psia (see steam table) (3)

$$\text{pp of } H_2O \text{ above solution} = 2.049 \times \frac{100.0}{100.0 + 4.0 + 3.2 + 0.3}$$
$$= 1.906 \text{ psia}$$

$$\begin{array}{l} \text{Mol fraction of water vapor in flue} \\ \text{gas above scrubber top stage} \end{array} = \frac{1.906}{15.2} = 0.1254$$

$$\begin{array}{l} \text{Partial pressure of water vapor in} \\ \text{flue gas at stack exit, psia} \end{array} \begin{array}{l} = 14.7 \times 0.1254 \\ = 1.8434 \text{ psia} \end{array}$$

Ambient air temperature, °F	35
Relative humidity of ambient air, %	45

Case	See Figure 47	Speci-fied	See Figure 48
Water temp on scrubber top stage, °F	120	–	125
Partial pressure of water vapor in flue gas at stack exit, psia	1.692	1.8434	1.941
Reheater exit gas temperature for zero water plume potential, °F	232	251	263

By interpolation, the reheater exit gas temperature for zero water plume potential is estimated to be 251°F for the conditions specified.

Accuracy of Estimated Critical Flue Gas Temperatures

How closely do the predicted critical temperatues associated with incipient plume formation compare with the actual temperatures? The answer to this question is suggested in part by TVA pilot-plant studies at temperatures ranging from 57° to 85°F. While the pilot-plant runs were not designed to test the precision of estimating the "critical" flue gas temperature, the studies did suggest that the estimating procedure is directionally reliable and reasonably accurate. TVA has not operated at low ambient air temperature since this estimating procedure was devised; hence, a validity check under severe conditions must await later pilot-plant operations.

Crocker (21) and Kalika (22) have suggested an alternative procedure for estimating the "critical" flue gas temperature to avoid a water plume when the flue gas mixes with cold air. According to their procedure, a pschrometric chart can be used by constructing an operating line tangent to the curve of 100% relative humidity. This line tangent to the curve passes through the ambient air temperature and relative humidity. The tangent, or operating line, is extrapolated in a tedious procedure to estimate the critical flue gas temperature necessary to avoid plume formation. Accuracy of the estimate is inherently limited since an error in constructing a line tangent to the saturation curve is magnified by the extrapolation required. Nevertheless, critical reheat temperatures, estimated according to this study and according to the procedure employed by Crocker and Kalika are in surprisingly good agreement as shown by Figure 52. The twenty comparisons plotted on Figure 52 are the scrubber temperatures ranging from 120° to 140°F in 5°F increments. Comparisons are made for ambient air of 40° and 60°F, and relative humidity of zero and 80%. In estimating the critical temperature according to Crocker and Kalika, a typical molecular weight of 30.6 was assumed for dry flue gas.

Data plotted in Figure 52 indicate that the two methods of estimating the critical reheat temperature (this study versus psychrometric chart) give almost identical temperatures at the 150°F level. At the 400°F temperature level, the critical reheat temperature estimated from the psychrometric chart is 25° to 30°F higher than estimates made from the procedure developed in this study. The differences in the estimates for the two procedures are doubtless accounted for, in part, by the assumptions made and by the mechanics of using the psychrometric chart.

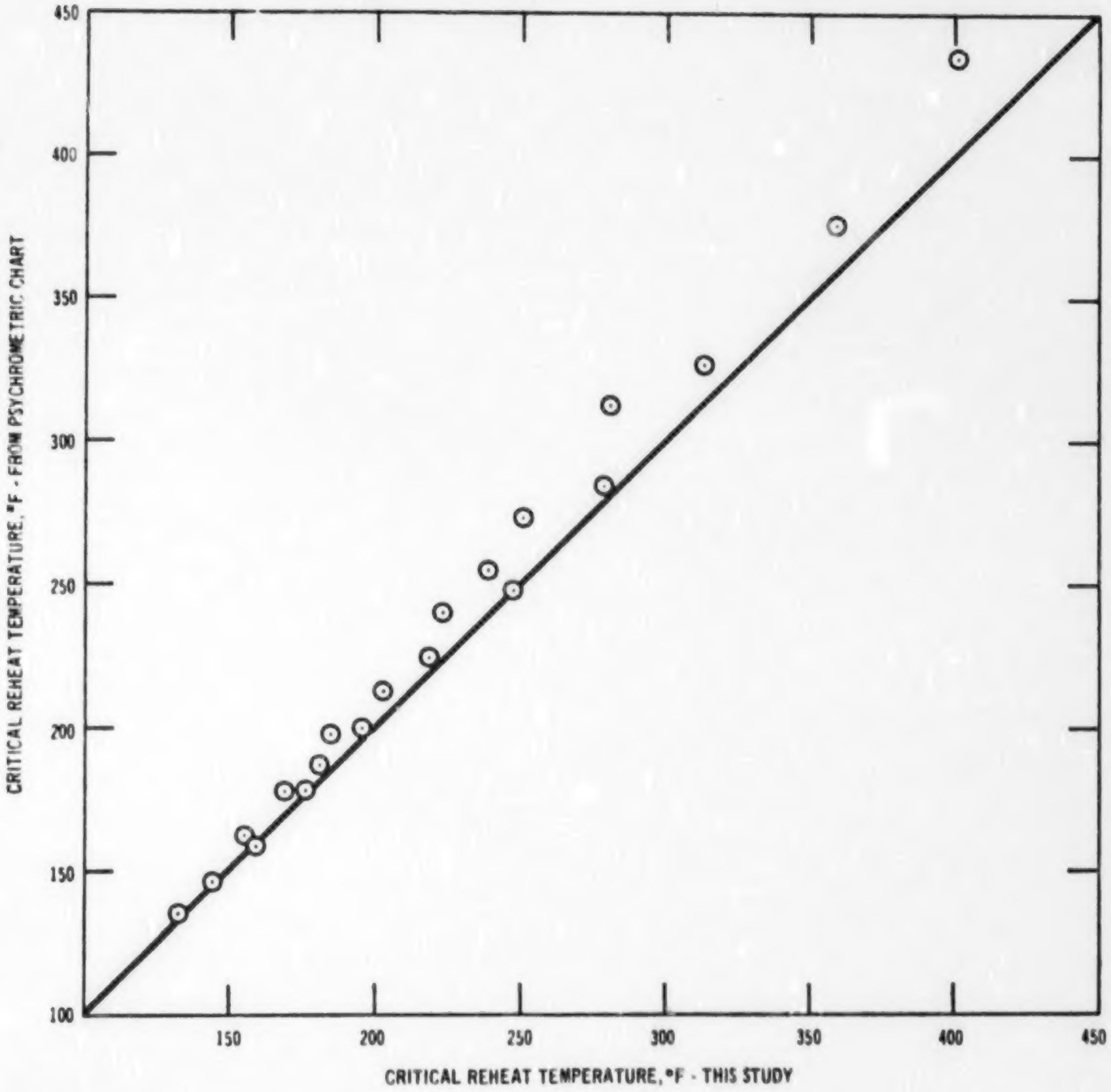

FIGURE 52

Critical Stack Gas Temperature, for Zero Water Plume – Comparison of Estimates